Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Pretreatment Facility

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Prepared by the
U.S. Department of Energy
Office of River Protection
Richland, Washington, 99352

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Summary

The U.S. Department of Energy (DOE), Office of River Protection (ORP) and the DOE Office of Environmental Management (EM), Office of Project Recovery has completed a Technology Readiness Assessment (TRA) for the Hanford Waste Treatment and Immobilization Plant (WTP) Pretreatment (PT) Facility. The purpose of this assessment was to determine if the maturity of critical technology elements (CTE) in the PT Facility is sufficient for these CTEs to be incorporated into the final design of this facility.

The methodology used for this TRA was based upon detailed guidance for conducting TRAs contained in the Department of Defense (DoD), *Technology Readiness Assessment Deskbook*[1]. The assessment utilized a slightly modified version of the Technology Readiness Level (TRL) Calculator[2] originally developed by Nolte et al. (2003) to determine the TRL for the CTEs. See Section 1.1, Table 1.1 for a discussion on the TRL scale used.

The TRA consisted of three parts:

1. Identifying the CTEs
2. Assessing the TRLs of each CTE using the technical readiness scale used by DoD and the National Aeronautics and Space Administration (NASA) and adapted by the Assessment Team for use by DOE
3. Evaluating, if required, technology testing or engineering work necessary to bring immature technologies to appropriate maturity levels.

CTEs are those technologies that are essential to successful operation of the facility, and are new or are being applied in new or novel ways or environments. The CTE identification process was based upon the definition of WTP systems, and 33 systems were considered from the PT Facility. A determination of the CTEs is presented in Appendix A. The nine PT Facility systems identified as CTEs are:

- Cesium Nitric Acid Recovery Process System (CNP)
- Cesium Ion Exchange Process System (CXP)
- Waste Feed Evaporation Process System (FEP)
- Treated LAW Evaporation Process System (TLP)
- Ultrafiltration Process System (UFP)
- Pulse Jet Mixer (PJM) system
- Waste Feed Receipt Process System (FRP)
- HLW Lag Storage and Feed Blending Process System (HLP)
- Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD)

The Assessment Team evaluated the TRL of each CTE against a scale developed for this assessment that is consistent with the scales originally developed by NASA and the DoD. The DoD and NASA normally

[1] DoD 2005, *Technology Readiness Assessment (TRA) Deskbook*, Department of Defense, prepared by the Deputy Undersecretary of Defense for Science and Technology, May 2005

[2] Nolte, William L., et al., *Technology Readiness Level Calculator*, Air Force Research Laboratory, presented at the National Defense Industrial Association Systems Engineering Conference, October 20, 2003

require TRL 6 for incorporation of a technology into the design process. This is done based on the recommendations of an influential report[3] by the U.S. Government Accountability Office (GAO) that examined the differences in technology transition between the DoD and private industry. It concluded that the DoD takes greater risks and attempts to transition emerging technologies at lesser degrees of maturity than private industry. The GAO also concluded that use of immature technology increased the overall program risk and recommended that the DoD adopt the use of NASA's TRLs as a means of assessing technology maturity prior to transition into final design. Based on the precedence set by the DoD, this assessment used TRL 6 as the basis for determining that a technology is sufficiently mature for incorporation into the final design.

The Assessment Team used a TRL Calculator, which is a software program, to provide a structured, consistent assessment to determine the TRL of each identified CTE. The TRL Calculator tabulates the responses to a standard set of questions addressing the hardware, software program, and manufacturability. The TRL Calculator is implemented in Microsoft Excel™ and produces a graphical display of the TRL achieved. It was adapted for this assessment by adding to and modifying the existing questions to make them more applicable to DOE waste treatment equipment and processes. The TRL Calculator is described in Appendix B. The specific responses to each of the TRL questions for each CTE evaluated in this TRA are presented in Appendix C. The CTEs were not evaluated to determine if they had matured beyond TRL 6.

The TRL for each of the nine CTEs evaluated is presented in Section 3, Table 3.1. This table presents the CTE and description; TRL rating based on the TRL scale presented in Section 1, Table 1.1; and the rationale for the TRL rating.

Based on the results of this TRA, the assessment team concluded the following:

- Cesium Nitric Acid Recovery Process System (CNP). The CNP is used for the recovery of nitric acid generated from the elution of the Cesium Ion Exchange Process System (CXP). The recovered nitric acid is recycled back to the CXP. The CNP was determined to be immature (e.g., TRL 3) due to the design concept which requires a unique process control system. The CNP has not been demonstrated by testing or analysis. The CNP concept may not be viable based on the changing process conditions (e.g., neutralization of the CNP separator product, change to resorcinol formaldehyde [RF] ion exchange [IX] resin.)
- Cesium Ion Exchange Process System (CXP). The CXP is used to recover cesium-137 from filtered low-activity waste (LAW). The CXP was determined to be mature (e.g., TRL 5) due to the advanced development of the CXP engineering concept and technology testing. The CXP can be fully matured (e.g., TRL 6) following completion of resorcinol formaldehyde testing and documentation, and testing of the ion exchange column functional requirements (e.g., resin removal, hydrogen gas venting). Redesign of vessel CXP-VSL-00001 to include mixing, chemical addition, and heating/ cooling capability is also required to effectively process solids generated from precipitation reactions in the filtered LAW.
- Waste Feed Evaporation Process System (FEP). The FEP evaporator design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site and is based on extensive lab-scale and pilot-scale prototypic testing has been completed to demonstrate this technology. The FEP evaporator is a mature technology. Vessels in the FEP (FEP-VSL-00017A/17B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs

[3] GAO/NSIAD-99-162, *Best Practices: Better Management of Technologies can Improve Weapon System Outcomes*, U.S. Government Accountability Office, July 1999

of these vessels, and the FEP, are determined to be immature (e.g., TRL 4) until these mixing issues on the pulse jet mixers (PJM) are resolved.

- Treated LAW Evaporation Process System (TLP). The TLP evaporator design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site, and is based on extensive lab-scale and pilot-scale prototypic testing that has been completed to demonstrate this technology. The TLP evaporator is a mature technology. Vessels in the TLP (TLP-VSL-00009A/9B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the TLP, are determined to be immature (e.g., TRL 4) until these mixing issues on the PJMs are resolved.
- Ultrafiltration Process System (UFP). The UFP is used to separate high-level waste (HLW) solids from liquids, and wash and leach the HLW solids to reduce their mass. The UFP is determined to be an immature technology (e.g., TRL 3) because the proposed process flowsheet has not been tested on a laboratory scale in an integrated test, and the design of the UFP process flowsheet and equipment system is still being completed. Plans are in place to test, evaluate, and select a final process flowsheet and equipment configuration to demonstrate the UFP.
- Pulse Jet Mixer (PJM) System. The PJM is a fluidic device used to mix process fluids in selected process vessels located in PT and HLW Facilities black cells. The PJM concept was based on previous applications at the Sellafield site in the United Kingdom. The PJM was determined to be immature (e.g., TRL 4) because the design requirements for the PJM technology have not been clearly and completely documented. Extensive testing has been completed to support final PJM design requirements on vessels that are anticipated to contain high solids concentrations (e.g., UFP-VSL-00002A/2B, HLP-VSL-000027A/27B, HLP-VSL-000028). No testing has been completed to support the final design of vessels anticipated to contain low solids concentrations. However, testing is planned. The Contractor has also identified vessels in which the PJM design will not meet basic mixing requirements (e.g., FRP-VSL-00002A/2B/2C/2D, HLP-VSL-00028, PWD-VSL-00044). Other vessels will not meet basic mixing requirements when 50% of the PJMs are operated as in a post-design basis event (e.g., FEP-VSL-00017A/17B, PWD-VSL-00033, PWD-VSL-00043, UFP-VSL-00001A/1B, CXP-VSL-00004, PWB-000015, PWD-VSL-000016, RDP-VSL-00002A/2B/2C, TCP-VSL-00001, TLP-VSL-00009A/9B).
- Waste Feed Receipt Process System (FRP). The FRP is used to receive low solids containing wastes (e.g., less than 3.8 wt%) from the tank farm into the PT Facility. The FRP is mixed using PJMs. The PJMs in the FRP were determined to be an immature technology (e.g., TRL 4) due to the inadequate design of the PJMs as determined by the Contractor based on engineering analysis. No testing has been completed to support the final design of vessels anticipated to contain low solids concentrations. However, testing is planned.
- Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD). The PWD and RLD are used to collect and manage process cycles, process line flushes, equipment flushes, and sump drains fluids in the PT. The PJMs in the PWD and RLD were determined to be an immature technology (e.g., TRL 4) due to the inadequate design of the PJMs as determined by the Contractor based on engineering analysis. No testing has been completed to support the final design of vessels anticipated to contain low solids concentrations. However, testing is planned.

Based upon the results of this assessment, the following recommendations for specific technologies are made:

Recommendation 1

Design activities associated with the CNP should be discontinued until: (1) a reassessment of the design and operational requirements for the CNP is completed; (2) the engineering specification for the CNP is revised to reflect operational conditions; and (3) the technology concept, which includes the process equipment and control system, is demonstrated through integrated prototypic testing.

Rationale

The design concept for the CNP evaporator has not been previously used in radioactive operations for the recovery of nitric acid, or proven by the Contractor in testing. Engineering calculations for the system design do not represent the variable feed compositions from the CXP and resultant product composition anticipated in the CNP. The CNP nitric acid product will likely require compositional adjustment to support subsequent reuse as an elution agent. The proposed continuous operation of the CNP will not accommodate this required chemical adjustment. Thus, the system as conceptualized appears to be undersized and may not support the waste treatment rate requirements of the PT Facility. This process design deficiency appears to be the result of the "Pretreatment Reconfiguration" studies that removed two CNP feed vessels and two CNP acid product vessels from the plant flowsheet.

Recommendation 2

The CNP should be functionally tested prior to installation in the black cell. The testing should include: testing with representative process feed compositions; verifying the process control system concept; verifying the ability to control and monitor the composition of the nitric acid product; demonstrating the cesium decontamination factor of 5 million; and demonstrating the ability to adequately decontaminate the demister pads using the sprays installed in the separator vessel.

Rationale

The CNP is not planned to be tested until cold commissioning. The CNP will be installed in a black cell and will be very difficult to modify after installation because of accessibility. Testing prior to installation will demonstrate the adequacy of the design and minimize post-installation modifications.

Recommendation 3

Prototypic equipment testing should be completed prior to continuing design of the hydrogen venting subsystem (nitrogen inerting and hydrogen gas collection piping system, and control system) for removing hydrogen and other gases from the cesium IX columns to demonstrate this design feature over the range of anticipated operating conditions.

Rationale

Integrated testing of all CXP technology components has not been completed. Major components not tested include the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns, and the capability to remove 99% by volume of the spherical RF resin from a prototypic IX column. The hydrogen venting system is a first-of-a-kind engineered design that is essential to safe operations of the CXP. Without proper functioning of this system, the CXP may not meet its required waste treatment rate performance objectives.

Alternatively, the project should consider re-designing (and testing) the hydrogen venting subsystem for the IX columns in order to simplify the system. For example, a small recycle stream from the IX columns to the feed vessel (CXP-VSL-00001) could be used to vent gases from the columns. The recycle stream could be controlled through the use of orifice plates and stop valves for isolation.

Recommendation 4

The adequacy of the design concept for CXP-VSL-00001 should be reevaluated and a determination made if this vessel should be modified to include mixing, chemical addition, and heating/cooling to mitigate anticipated process flowsheet issues with precipitation of solids in the CXP feeds.

Rationale

Bechtel National, Inc. engineering studies conducted in 2005 and 2007 indicate that precipitation of sodium oxalate and gibbsite solids will occur following filtration. The capability of the CXP to effectively treat feeds that contain freshly precipitated sodium oxalate and gibbsite solids is not known. Understanding of the dissolution and precipitation kinetics for sodium oxalate and gibbsite is lacking. The morphology of freshly precipitated sodium oxalate is not completely understood. The CXP-VSL-00001 has no capability for blending solutions or suspending solids. Flowsheet modeling indicates that solids are likely to precipitate if chemical adjustments are not made to the vessel. The CXP-VSL-00001 has no capability for chemical adjustments to reduce/mitigate the solids concentration in cesium IX feed or dissolve/remove solids. It is not clear that the CXP-VSL-00001 vessel design is adequate to perform its required function and support the waste treatment capacity requirements of the PT Facility.

Recommendation 5

Development and testing at a laboratory-scale with actual wastes, and at an engineering-scale with simulants, should be completed in prototypical process and equipment testing systems to demonstrate all detailed flowsheets for the UFP prior to final design. The testing should validate the scaling methodology for mixing, chemical reactions, and filter surface area sizing; determination of process limits; and recovery from off-normal operating events.

Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-12, "Undemonstrated Leaching Process," and WTP Baseline testing of the Oxidative Leaching Process.

Rationale

Previous DOE evaluations (D-03-DESIGN-05) have been completed on the adequacy of the UFP process chemistry and ultrafilter sizing. This assessment concluded that the WTP flowsheet was not adding sufficient sodium hydroxide to support the dissolution of aluminum in the HLW sludge and the ultrafilter surface area was undersized by a factor of about 2.6. Partial planning is in place by the Contractor to conduct technology testing to provide the technical basis for the ultrafiltration flowsheet and equipment design.

Recommendation 6

Evaluation of a vertical modular equipment arrangement for the UFP filter elements for increasing the filter surface area should be continued. The design configuration (currently proposed horizontal or vertical orientation of the filters) that has the highest probability of successfully achieving performance requirements should be thoroughly tested in high fidelity, prototypical engineering-scale tests using

simulants that represent a range of tank waste compositions. Testing scope should include all filtration system operations, process flowsheets (caustic and oxidative leaching and strontium/transuranic precipitation), high-temperature filtration, and filter back pulsing, cleaning, draining, and replacement. Based on the results of this testing, a design concept (either the horizontal arrangement proposed by the Contractor or the vertical arrangement conceptualized by Energy*Solutions*) should be selected for final design.

Rationale

A review and assessment of a proposed modified ultrafiltration system design was conducted by the Contractor. This design concept was based on deploying five filter elements (two 10 ft sections and three 8 ft sections) in a nominally horizontal arrangement as a single fabricated unit. The expert review team advised that:

- The proposed new arrangement for the ultrafilter with five modules connected in series may not provide sufficient drainage, and may cause problems with residual slurry solids buildup in the lower tubes of each module.
- The need to remove and discard a complete five-module filter system because of a blockage or partial blockage, and its replacement with a new unit, may be both lengthy and costly.
- An alternate vertical arrangement of filter modules was strongly recommended by the reviewers. Such an arrangement would trap residual solids within the tubes themselves and have the potential to allow the removal of individual modules or tube bundles.

Recommendation 7

Clear, quantitative, and documented mixing performance requirements for all PJM mixed vessels in the PT Facility and HLW Vitrification Facility should be established. The requirements should be established for all vessel systems even though only those associated with FRP, HLP, PWD, TLP, and FEP were discussed in this assessment.

These requirements should include requirements from criticality safety, environmental compliance, hydrogen management and mitigation, process control, process operations, and immobilized low-activity waste and immobilized high-activity waste form production. These requirements should be used to assess the adequacy of the design and operation of each of the PJM mixed vessels and provide a basis for the completion of the planned testing work on PJMs planned as part of Issue Response Plan M-3, "Inadequate Mixing System Design." These requirements should be established jointly with project personnel representing safety, environmental compliance, and process operations, with DOE as owner and operator of the WTP.

Rationale

The lack of requirements for mixing performance of each PJM mixed vessels does not provide a basis for:

- The Contractor's mixing design for the vessels and PJMs.
- DOE's assessment, as owner and operator of the WTP, of the adequacy of the WTP to achieve safety and operational requirements.
- The Contractor's planning and conduct of a technology testing program to generate PJM mixing test information to support design decisions (see Recommendation 8).

Recommendation 8

PJM demonstration testing should be completed. The testing information, supplemented with analysis, should be used to determine the design capability of each PJM mixed vessel and identify any required design changes.

Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-3, "Inadequate Mixing System Design."

Rationale

The Contractor has developed a testing program on the PJMs to assess the adequacy of the design and operation of each of the PJM mixed vessels.

The following supporting recommendations are made by the Assessment Team. These recommendations supplement the major recommendations presented in the previous section.

1. The specific gravity operating limit for controlling the concentrated cesium eluate in the CNP separator to a maximum of 80% saturation should be re-evaluated. Based on the WTP Contractor's plan to neutralize cesium concentrate in the separator, and thereby create solids, this operating constraint may not be required.
2. The engineering specification for the CNP should be modified to include (1) the estimated variable feed composition and (2) factory acceptance testing to demonstrate removal and installation of the demister pads from the separator vessel.
3. The Contractor should reassess the corrosion evaluations for the CNP vessels and piping based on the operating conditions of the system.
4. Testing of spherical RF resin should be conducted to: (1) assess physical degradation for irradiated resin samples; (2) assess effects from anti-foaming agent and separate organics present in the feed to the CXP; and (3) assess the impact of particulates on IX column performance.
5. All currently planned testing and documentation of test results for spherical RF resin should be completed. (*Note: This planned work is in the WTP Baseline.*)
6. Additional research should be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate.
7. The engineering specification for the IX columns should be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the External Flowsheet Review Team recommendations for the CXP.
8. The engineering specification for the CXP should be modified to include factory acceptance testing of the IX column to demonstrate that the system is capable of removing greater than 99% by volume of resin from the IX column, upon completion of the resin removal mode, using a maximum volume of 7,500 gallons of water to displace the resin.
9. The strategy and method to scale the ultrafiltration processes (mixing, chemical reaction, and filter surface area) to predict performance of the ultrafiltration system should be established to ensure a high-fidelity UFP engineering-scale test platform and support useful interpretation of the testing results.

10. Process modeling to project the performance of the WTP and confirm design capability should use realistic assumptions on the effectiveness of mixing (both time and efficiency of mixing).

11. An evaluation of the fluids to be received and mixed in the feed receipt vessels (FRP-VSL-00002A/B/C/D) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

12. An evaluation of the fluids to be received and mixed in the HLW feed receipt vessel (HLP-VSL-00022) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

Contents

Figures

Tables

Acronyms and Abbreviations

Al	aluminum
APEL	Applied Process Engineering Laboratory
BNFL	British Nuclear Fuels Limited, Inc.
BNI	Bechtel National, Inc.
BV	bed volume
Ca	calcium
CBT	cone-bottom tank
CFD	Computational Fluid Dynamic
CNP	Cesium Nitric Acid Recovery Process System
Cr	chromium
CRP	Cesium Resin Addition Process System
CRV	concentrate receipt vessel
Cs	cesium
CTE	critical technology element
CUF	cells unit filter
CXP	Cesium Ion Exchange Process System
DBE	design basis event
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EARP	Enhanced Actinide Removal Plant
EFRT	External Flowsheet Review Team
EM	Office of Environmental Management
ESP	Environmental Simulation Program
ETF	Effluent Treatment Facility
FEP	Waste Feed Evaporation Process System
FRP	Waste Feed Receipt Process System
GAO	U.S. Government Accountability Office
GR&R	gas retention and release
HLP	HLW Lag Storage and Feed Blending Process System
HLW	High-Level Waste [Facility]
HNO_3	nitric acid
ID	inner diameter
ILAW	immobilized low-activity waste
IRP	Issue Response Plan
IX	ion exchange
K	potassium
LAW	Low Activity Waste [Facility]
LERF	Liquid Effluent Retention Facility
LS	Large-Scale
MnO_4	permanganate
Na	sodium
$NaMnO_4$	sodium permanganate
$NaNO_3$	sodium nitrate
NaOH	sodium hydroxide
NAS	sodium alumino-silicate
NASA	National Aeronautics and Space Administration
NO_3	nitrate
NPH	normal paraffin hydrocarbon

OD	outer diameter
OH	hydroxide
ORP	Office of River Protection
PJM	pulse jet mixer
PNWD	Pacific Northwest Division
PT	Pretreatment [Facility]
Pu	plutonium
PUREX	Plutonium-Uranium Extraction (Plant)
PWD	Plant Wash and Disposal System
RDP	Spent Resin Collection/Dewatering Process System
RF	resorcinol formaldehyde
RLD	Radioactive Liquid Waste Disposal System
SBS	submerged bed scrubber
SIPP	Semi-Integrated Pilot Plant
Sr	strontium
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SS-PJM	small-scale-pulsed jet mixer
TBP	tri-butyl phosphate
TCP	Treated LAW Concentrate Storage Process System
TFC	Tank Farm Contractor
TLP	Treated LAW Evaporation Process System
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TRU	transuranic
U	uranium
UFP	Ultrafiltration Process System
UKAEA	United Kingdom Atomic Energy Agency
WTP	Waste Treatment and Immobilization Plant
ZOI	zone of influence

Units of Measure

acfm	actual cubic feet per minute
bar	metric unit of atmospheric pressure [barometric]
cP	centipoise
ft	foot
ft^2	square foot
g	gram
gpm	gallons per minute
Kgal	thousand gallon
L	liter
m	meter
m^2	square meter
m^3	cubic meter
ml	milliliter
M	molar
Mgal	million gallon
MT	metric ton
Pa	pascal
ppm	parts per million
psi	pounds per square inch
psia	means pound per square inch *absolute*
psig	pounds per square inch gauge
sec	second
vol%	volume percentage
wt%	weight percentage

Glossary

Critical Technology Element	A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel. Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.
Engineering-Scale	A system that is greater than 1/10 of the size of the final application, but it is still less than the scale of the final application.
Full-Scale	The scale for technology testing or demonstration that matches the scale of the final application.
Identical System	Configuration that matches the final application in all respects.
Laboratory-Scale	A system that is a small laboratory model (less than 1/10 of the size of the full-size system.
Model	A functional form of a system generally reduced in scale, near or at operational specification.
Off-Bottom Suspension	A condition in which the solids that settle to the bottom of the vessel in the suction phase are re-suspended in the drive phase.
Operational Environment (Limited Range)	A real environment that simulates some of the operational requirements and specifications required of the final system (e.g., limited range of actual waste).
Operational Environment (Full Range)	Environment that simulates the operational requirements and specifications required of the final system (e.g., full range of actual waste).
Paper System	System that exists on paper (no hardware).
Pieces System	System that matches a piece or pieces of the final application.
Pilot-Scale	The size of a system between the small laboratory model size (bench-scale) and a full-size system.
Prototype	A physical or virtual model that represents the final application in almost all respects that is used to evaluate the technical or manufacturing feasibility or utility of a particular technology or process, concept, end item, or system.
Relevant Environment	Testing environment that simulates the key aspects of the operational environment; e.g., range of simulants plus limited range of actual waste.
Similar System	Configuration that matches the final application in almost all respects.
Simulated Operational Environment	Environment that uses a range of waste simulants for testing of a virtual prototype.
50/50	Designation of the percentage of the number of pulse jet mixers that will be in operation at any one time following a design basis event for selected vessels. This currently applies to the vessels that contain low solid concentrations (e.g., below 16.7 wt% solids).

1.0 Introduction

1.1 Background

The U.S. Department of Energy (DOE), Office of River Protection (ORP) is constructing a Waste Treatment and Immobilization Plant (WTP) for the treatment and vitrification of the underground tank wastes stored at the Hanford Site in Washington State. The WTP Project is comprised of four major facilities: a Pretreatment (PT) Facility to separate the tank waste into high-level waste (HLW) and low-activity waste (LAW) process streams; a HLW Vitrification Facility to immobilize the HLW fraction; a LAW Vitrification Facility to immobilize the LAW fraction; and an Analytical Laboratory to support the operations of all four treatment facilities. Additionally, there are the Balance of Facilities operations that provide utilities and other support to the processing facilities. The WTP Project is DOE's largest capital construction project with an estimated cost of $12.263 billion, and a project completion date of November 2019 (DOE 2006).

Issues associated with the maturity of technology in the WTP have been evaluated by independent DOE Review Teams and in DOE's design oversight process. The most notable evaluation was the recently completed "Comprehensive External Review of the Hanford Waste Treatment Plant Flowsheet and Throughput" (CCN:132846) completed in March 2006. This evaluation identified 28 separate technical issues, some of which had not been previously identified by the WTP Contractor (Bechtel National Inc. [BNI]) or DOE. A number of these issues originated from limited understanding of the technologies that comprise the WTP flowsheet.

As a result of these reviews, and DOE's desire to more effectively manage the technology risks associated with the WTP, DOE decided to conduct a Technology Readiness Assessment (TRA) to assess the technical maturity of the WTP design. This TRA is patterned after guidance established by the U.S. Department of Defense (DoD) (DoD 2005) for conducting TRAs.

1.2 Assessment Objectives

The purpose of this TRA is to evaluate the technologies used in PT Facility. This TRA:

- Identifies critical technology elements (CTE)
- Determines the TRL associated with the CTEs
- Provides recommendations on how to improve the maturity level of technologies that require additional development.

The TRA was performed jointly by DOE ORP and the DOE Office of Environmental Management (EM), Office of Project Recovery.

1.3 Pretreatment Facility Flowsheet

The PT Facility flowsheet is shown in Figure 1.1. This flowsheet provides the relationship of the systems that were evaluated in this TRA. Essentially all process systems were evaluated. The vessel batch capacities and selected process design conditions are indicated on the flowsheet. Additional detail on these systems is presented in Section 2.3.

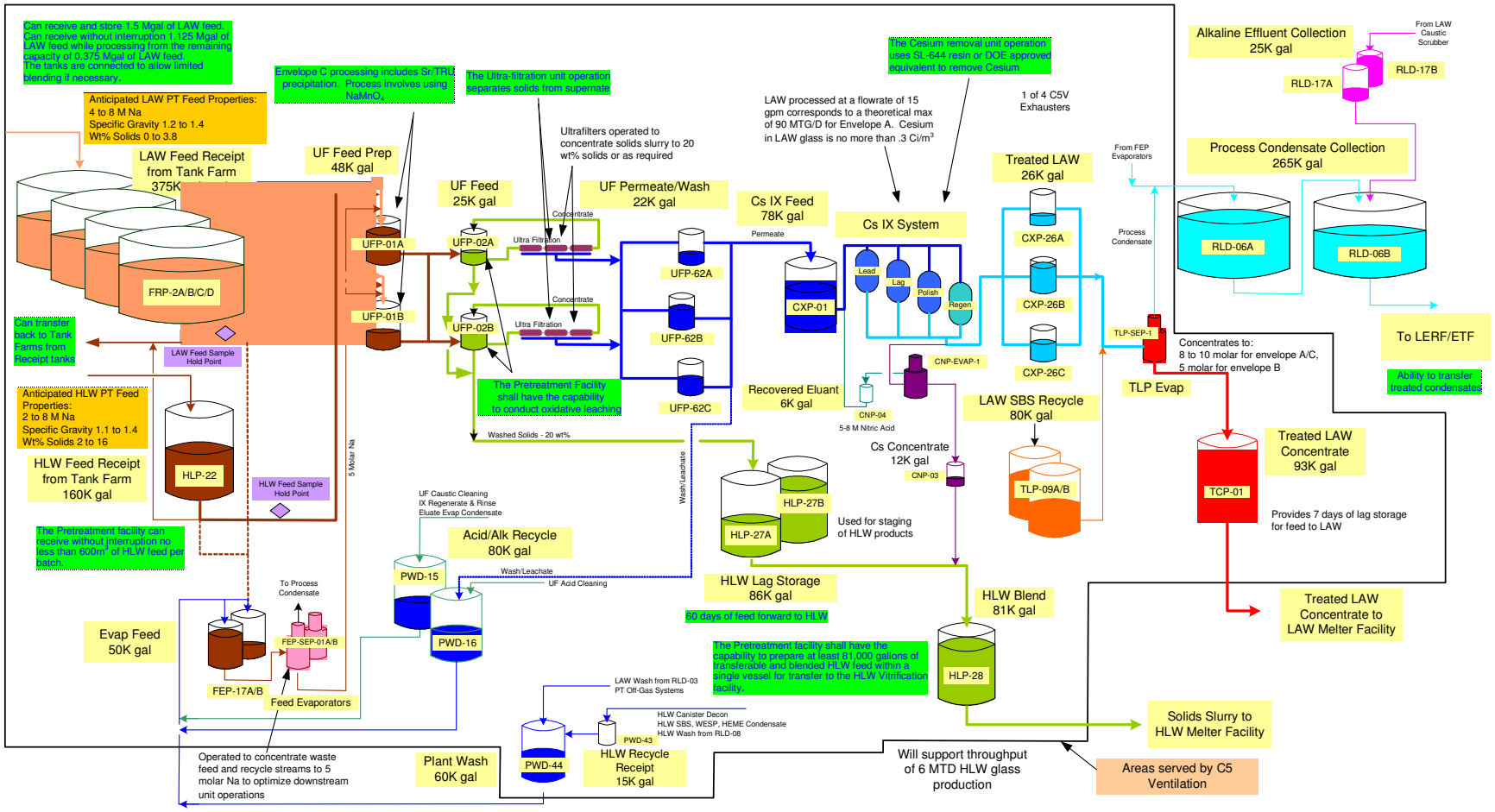

Figure 1.1. WTP Pretreatment Facility Flowsheet

1.4 Description of TRA Process

1.4.1 Background

> "A TRA is a systematic, metric-based process and accompanying report that assesses the maturity of certain technologies [called Critical Technology Elements (CTEs)] used in systems." (DoD 2005)

In 1999, the U.S. General Accounting Office (GAO) produced an influential report (GAO/NSIAD-99-162) that examined the differences in technology transition between the DoD and private industry. The GAO concluded that the DoD took greater risks, and attempted to transition emerging technologies at lesser degrees of maturity compared to private industry, and that the use of immature technology increased overall program risk and led to substantial cost and schedule overruns. The GAO recommended that the DoD adopt the use of National Aeronautics and Space Administration's (NASA) Technology Readiness Levels (TRL) as a means of assessing technology maturity prior to design transition (see Appendix A for further discussion).

In 2001, the Deputy Undersecretary of Defense for Science and Technology issued a memorandum that endorsed the use of TRLs in new major programs. Guidance for assessing technology maturity was incorporated into the *Defense Acquisition Guidebook* (DODI 5000.2). Subsequently, the DoD developed detailed guidance for using TRLs in the 2003 *DoD Technology Readiness Assessment Deskbook* (updated in May 2005 [DOD 2005]). The DoD Milestone Decision Authority must certify to Congress that the technology has been demonstrated in a relevant environment prior to transition of weapons system technologies to design or justify any waivers. TRL 6 is also used as the level required for technology insertion into design by NASA.

Based upon historical use of the TRA process, the DOE has decided to use the DoD TRA process as a method for assessing technology readiness for the WTP.

1.4.2 TRA Process

The TRA process as defined by the DoD consists of three parts: (1) identifying the CTEs; (2) assessing the TRLs of each CTE using an established readiness scale; and (3) preparing the TRA report. As some of the CTEs were judged to be below the desired level of readiness, the TRA was followed by a Technology Maturation Plan (TMP) analysis and report that determines the additional development required to attain the desired level of readiness (see Volume I). Requirements for the TMP analysis are described in the DoD *Technology Readiness Assessment Deskbook* (May 2005) and is usually carried out by a group of experts that are independent of the project under consideration.

The CTE identification process involves breaking the project under evaluation into its component systems and subsystems, and determining which of these are essential to project success and either represent new technologies, combinations of existing technologies in new or novel ways, or will be used in a new environment. Appendix B describes the CTE process in detail.

The TRL scale used in this assessment is shown in Table 1.1. The scale is based on the DoD and NASA scales. Minor modifications have been made to reflect the chemical processing nature of the WTP. The scale requires that testing of a prototypical design in a relevant environment be completed prior to incorporation of the technology into the final design of the facility.

Table 1.1. Technology Readiness Levels used in this Assessment

Relative Level of Technology Development	Technology Readiness Level	TRL Definition	Description
System Operations	**TRL 9**	Actual system operated over the full range of expected conditions.	Actual operation of the technology in its final form, under the full range of operating conditions. Examples include using the actual system with the full range of wastes.
System Commissioning	**TRL 8**	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental testing and evaluation of the system with real waste in hot commissioning.
	TRL 7	Full-scale, similar (prototypical) system demonstrated in a relevant environment.	Prototype full-scale system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in a relevant environment. Examples include testing the prototype in the field with a range of simulants and/or real waste and cold commissioning.
Technology Demonstration	**TRL 6**	Engineering/pilot-scale, similar (prototypical) system validation in a relevant environment.	Representative engineering-scale model or prototype system, which is well beyond the lab-scale tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype with real waste and a range of simulants.
	TRL 5	Laboratory-scale, similar system validation in relevant environment	The basic technological components are integrated so that the system configuration is similar to (matches) the final application in almost all respects. Examples include testing a high-fidelity system in a simulated environment and/or with a range of real waste and simulants.
Technology Development	**TRL 4**	Component and/or system validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in a laboratory and testing with a range of simulants.
Research to Prove Feasibility	**TRL 3**	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. Components may be tested with simulants.
	TRL 2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies.
Basic Technology Research	**TRL 1**	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.

The testing requirements used in this assessment are compared to the TRLs in Table 1.2.
These definitions provide a convenient means to understand further the relationship between the scale of testing, fidelity of testing system, and testing environment and the TRL. This scale requires that for a TRL 6, testing must be completed at an engineering- or pilot-scale, with a testing system fidelity that is similar to the actual application and with a range of simulated wastes and/or limited range of actual waste, if applicable.

The assessment of the TRLs was aided by a TRL Calculator that was originally developed by the U.S. Air Force (Nolte et al. 2003), and modified by the Assessment Team. This tool is a standard set of questions addressing hardware, software, program, and manufacturability questions that is implemented in Microsoft Excel™. The TRL Calculator produces a graphical display of the TRLs achieved. The TRL Calculator used in this assessment is described in more detail in Appendix B.

Table 1.2. Relationship of Testing Requirements to the TRL

TRL	Scale of Testing[1]	Fidelity[2]	Environment[3]
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot	Similar	Relevant
5	Lab	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	

1. Full-Scale = Full plant scale that matches final application
   1/10 Full Scale < Engineering/Pilot-Scale < Full-Scale (Typical)
   Lab-Scale < 1/10 Full-Scale (Typical)
2. Identical System – configuration matches the final application in all respects
   Similar System – configuration matches the final application in almost all respects
   Pieces System – matches a piece or pieces of the final application
   Paper System – exists on paper (no hardware)
3. Operational (Full Range) – full range of actual waste
   Operational (Limited Range) – limited range of actual waste
   Relevant – range of simulants + limited range of actual waste
   Simulated – range of simulants

2.0 TRL Assessment

2.1 TRL Process Description

An Assessment Team comprised of staff from the DOE ORP, technical consultants to ORP, and DOE EM's Office of Project Recovery completed the TRL assessment with support from the WTP engineering staff (see Appendix D for the identification of the Assessment Team and supporting contractor staff from the WTP). Assessment Team staff have worked on the Hanford WTP project and related nuclear waste treatment and immobilization technologies for more than 30 years, and are independent of the WTP design and construction project.

The WTP engineering staff (e.g., WTP Project Team) presented descriptions of the WTP systems that were assessed, participated in the identification of the CTEs, and participated in the completion of responses to individual questions in the TRL Calculator. Each response to a specific Calculator question was recorded along with references to the appropriate WTP Project documents. The Assessment Team also completed independent due-diligence reviews and evaluation of the testing and design information to validate input obtained in the Assessment Team and WTP Project Team working sessions. The Calculator results for each CTE can be found in Appendix C.

This Assessment Team evaluated the process and mechanical systems that are planned for use in the WTP PT Facility. This assessment was focused on the adequacy of the equipment technologies that comprise the design. A detailed assessment of the process flowsheet chemistry was not completed as part of this assessment. The Assessment Team did not evaluate the software systems used to control the process and mechanical equipment because these software systems have not been sufficiently developed and are not critical to the mechanical design of the facilities. The assessment of the technology readiness of the software systems will be completed at a later date.

2.2 Determination of CTEs

The process for identification of the CTEs for the PT Facility involved two steps:

1. An initial screening by the Assessment Team of the complete list of systems in the PT Facility for those that have a potential to be a CTE. In this assessment, systems that are directly involved in the processing of the tank waste or and secondary wastes were initially identified as potential CTEs. The complete list of systems and those identified as potential CTEs are provided in Appendix A, Tables A.1.
2. A final screening of the potential CTEs was completed by the Assessment and WTP Project Teams to determine the final set of CTEs for evaluation. The potential CTEs were evaluated against the two sets of questions presented in Table 2.1. A system is determined to be a CTE if a positive response is provided to at least one of the questions in each of the two sets of questions.

Table 2.1. Questions used to Determine the CTEs for the Pretreatment Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	1. Is the technology (system) new or novel? 2. Is the technology (system) modified? 3. Has the technology been repackaged so that a new relevant environment is realized? 4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

The specific responses to each of the questions for each CTE are provided in Table B.5 of Appendix B. In this final assessment, the following systems were identified as CTEs:

- Cesium Nitric Acid Recovery Process System (CNP)
- Cesium Ion Exchange Process System (CXP)
- Ultrafiltration Process System (UFP)
- Treated LAW Evaporation Process System (TLP)
- Waste Feed Evaporation Process System (FEP)
- Pulse Jet Mixer (PJM) system
- Waste Feed Receipt Process System (FRP)
- HLW Lag Storage and Feed Blending Process System (HLP)
- Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD)

2.3 Summary of the Technology Readiness Assessment

A TRL assessment was completed for each CTE, and the results are summarized in this section.

The Calculator (Appendix B) employs a two-step process to evaluate TRLs:

1. A top-level set of questions is evaluated to determine the starting point, in terms of readiness level, for the TRL assessment.
2. A more detailed assessment was completed using a series of detailed questions starting at a TRL level one level below the expected outcome. The responses to the TRL criteria are provided in Appendix C for the highest level evaluated for each CTE.

For each CTE, the discussions below describe the CTE function, CTE description, the relationship to other CTEs, the development history and status, the relevant environment, a comparison of the demonstrated and relevant environments, and the rationale for the TRL determination and any recommendations.

2.3.1 Cesium Nitric Acid Recovery Process System (CNP)

2.3.1.1 Function of the CNP

The primary functions of the CNP are to: receive eluate from the Cesium Ion Exchange Process System (CXP); concentrate the eluate; transfer eluate concentrate to the HLW Lag Storage and Feed Blending Process System (HLP); and recover the evaporator overheads stream as nitric acid (HNO_3) eluent for reuse in the CXP.

2.3.1.2 Description of the CNP

The CNP is described in the *System Description for the Pretreatment Facility Cs Nitric Acid Recovery Process (CNP) System* (24590-PTF-3YD-CNP-00001). A block flow diagram of the CNP is provided in Figure 2.1.

Cesium (Cs) eluate and rinse water are sent from the Cs ion exchange (IX) process on a periodic basis to the Cs evaporator breakpot (CNPBRKPT-00002). The eluate received from the IX column is, on average, more dilute than the 0.5 M HNO_3 used for elution. In addition, the concentration of nitric acid will vary throughout the elution cycle starting with a more dilute concentration, reaching a maximum concentration, and ending with a more dilute concentration. This occurs because hydrogen ions are exchanged with eluted cations (aluminum [Al], calcium [Ca], Cs, potassium [K], sodium [Na], etc.) on the IX resin during the elution process and because some wash water (used for displacing residual caustic and nitric acid from the IX column) will precede and follow the eluate transfers to the evaporator. The breakpot may also receive infrequent transfers of eluate or concentrate from the eluate contingency storage vessel, CNP-VSL-00003.

The breakpot gravity feeds down to the Cs evaporator eluate lute pot, CNP-VSL-00001, which provides a vacuum seal between the breakpot and the Cs evaporator separator vessel, CNP-EVAP-00001. The separator vessel is initially charged with nominally 7.2 M HNO_3 (a range of 5 M to 8 M HNO_3 can be used). Cs eluate is fed at 6.9 to 10 gpm into the separator vessel and evaporated, leaving the salts contained in the eluate to concentrate in the separator vessel. The Cs evaporator concentrate reboiler, CNP-HX-00001, provides the heat transfer area required to transfer adequate heat to the process fluid to evaporate eluate at the same rate it is received in the separator vessel. The separator vessel contains built-in demister pads to remove aerosols formed during evaporation. The Cs evaporator separator vessel operates under vacuum at approximately 40 inches water (H_2O) absolute to reduce the boiling temperature of the liquor to approximately 122° to 140°F.

The CXP/CNP will operate at constant flow rates during elution/evaporation modes. The system is designed to operate from a flow rate of 6.9 to 10 gpm, but during the actual processing the flow rate is maintained constant, thus the evaporation rate/duty is constant throughout an IX column elution. There will be variation in the feed stream as far as the nitric acid concentration received in the evaporator; however, this is buffered first by the charge in the evaporator, and secondly by the large volume of 0.5 M nitric acid in CNP-VSL-00004. The system is controlled to recover nitric acid at 0.5 M, and a variation in the operating pressure allows for manipulation of the vapor equilibrium curve to obtain the desired concentration. In the event that adjustment to the nitric acid concentration is required, fresh nitric or water may be added to CNP-VSL-00004 at any time, and CNP-VSL-00004 may be discharged at anytime as long as a heel is maintained to provide the hydraulic seal necessary for the evaporator vacuum.

The system as designed will provide an unlimited elution supply, as the evaporator recovers nitric acid at the same rate the IX column is eluted. In the event that the evaporator is unavailable and the 6200 gallons is not adequate, fresh nitric acid from BOF may be supplied, and the eluate is sent to CNP-VSL-00003.

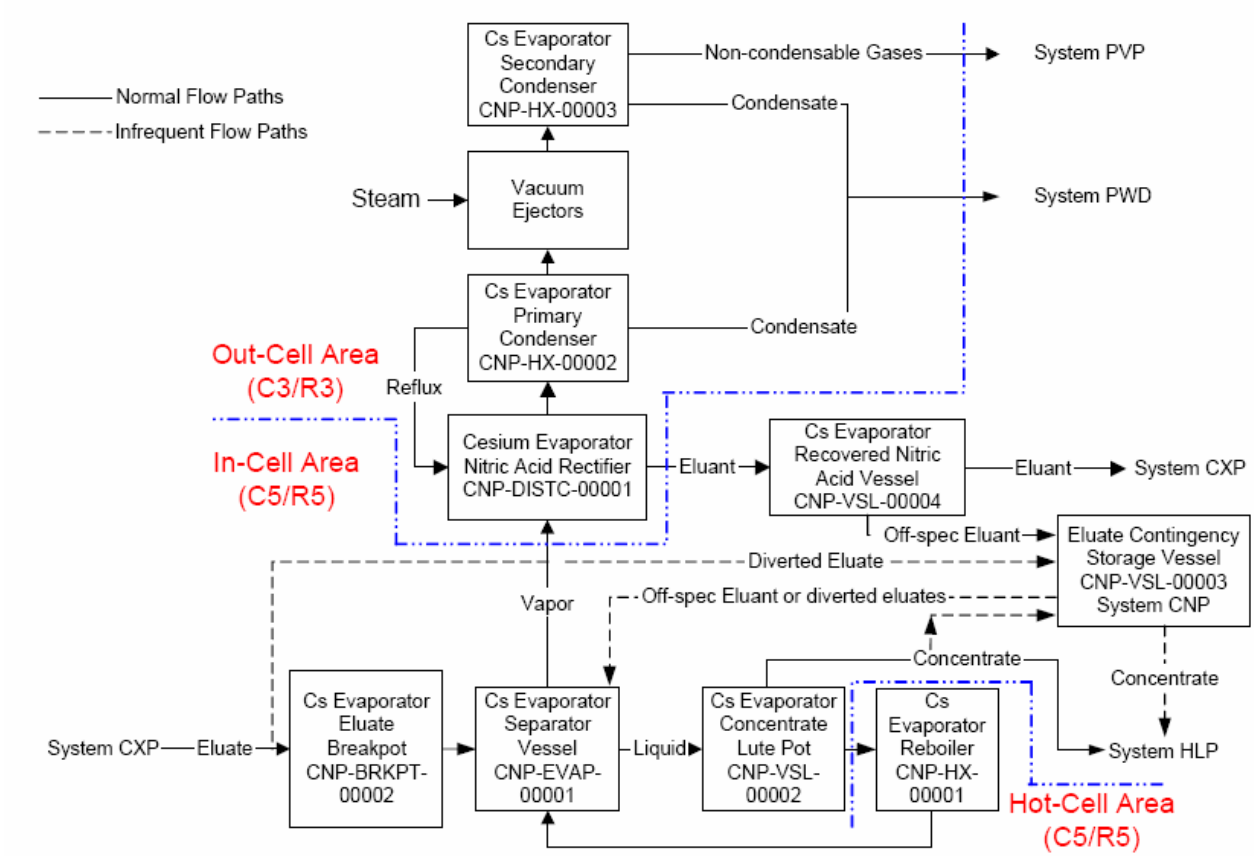

Figure 2.1. Block Flow Diagram for the Cesium Nitric Acid Recovery Process System

The following is a summary of the approach to be taken for operation and control of the CNP to continuously provide elution acid at or near 0.5 M nitric acid for elution of the IX columns:

- CNP-VSL-00004 is the elution acid feed vessel. This 10,000-gallon vessel (6,300 gallon batch volume) may be adjusted to 0.5 M by addition of 2 M HNO_3 after each elution cycle. The acid adjustment is confirmed by sampling the vessel contents. This would ensure that the correct acid strength is used at the start of each elution cycle. If required adjustments may be made after each elution cycle; however, the elution of an IX column may be successfully done with a range of acid concentrations (WTP-RPT-143, Rev 1) and operation of the CNP will allow for a range of concentration for efficient operations.

- At the beginning of the elution cycle, the column effluent is displaced rinse water and for the first 5 to 6 bed volumes there will be no acid fed to the CNP evaporator because the H^+ ions are loading on the resin as the sodium, Cs, and other cations are displaced (24590-101-TSA-W000-00004-99-00013 Rev. 00B; WTP-RPT-143, pg. 11.15).

- The elution column effluent is fed directly to the evaporator at 7 to 10 gpm and the concentration of the acid that is recovered in the acid recovery tower (CNP-DISTC-00001) is controlled as follows:

  – The evaporator is charged with about 1,800 gallons of 5 to 8 M HNO_3

- For every bottoms acid concentration, there will be a corresponding vapor acid concentration at the boiling point at constant pressure. This well-known equilibrium data is readily available and will be used to aid in control of the process. The equilibrium curve shifts as the evaporator pressure is changed and the equilibrium values can be derived for each pressure, giving a series of curves that relate the known bottoms concentration to the vapor concentration. Based on modeling, the overheads product will remain at a constant average for each concentration cycle, as the salts in the evaporator increase, the acid concentration decreases. However, the overheads product remains nearly constant at a set operating pressure.
- By changing the evaporator operating pressure, the acid concentration in the vapor can be controlled over a range for any given bottoms concentration.
- By vendor calculation 24590-QL-POA-MEVV-00002, *Hanford Evaporator Project #2-Evaporator Mass and Energy Balance Calculation*, pg. 7), CNP-DISTC-00001 will conservatively recover 98.5% of the acid from the vapor fed to the bottom of the tower.
- The recovered acid stream flows through a conductivity cell enroute to CNP-VSL-00004. This provides a continuous check on the recovered acid concentration. Earlier lab tests performed at Savannah River Site (SRS) showed the validity of using conductivity measurement to determine the nitric acid concentration around 0.5 M (WSRC-TR-2003-00135, Rev. 0, pg. 24).
- If the conductivity indicates low acid in the recovered acid stream, the evaporator operating pressure can be changed to shift the equilibrium in favor of recovering more acid. In this way, the recovered acid concentration can be maintained at or very near to 0.5 M. Modeling of the system indicates that minimal control will be required if initial conditions are set and maintained.
- In the event the evaporator pressure cannot be changed sufficiently and the recovered acid concentration drops slightly below 0.5 M, the acid routed to the IX column will still be near 0.5 M for more than the first 5 to 6 bed volumes due to the small dilution of the initial 6,000 to 8,000 gallons of 0.5 M acid in CNP-VSL-00004.
- As the salt content of the evaporator bottoms increases from elution to elution, the vapor/liquid equilibrium will be affected by the non-volatile solute and this will be taken into consideration along with the pressure variation.

Several batches of Cs eluate (up 10 to 13) are concentrated until the dissolved salt concentration reaches 80% of saturation when cooled to 25°C. Alternatively, the concentrate can be transferred to the HLP after each eluent recovery and concentration operation in smaller batches if required. The Cs concentrate is extracted from the Cs evaporator separator vessel by gravity feeding to the eluate lute pot, CNP-VSL-00002, where transfer ejectors send it to vessels HLP-VSL-00028 or HLP-VSL-00027B. If the HLP cannot accept additional volume at the time of a required transfer, vessel CNP VSL-00003 (batch capacity of 12,500 gallons) will receive the transfer. When the evaporator is shut down, purge air will be used to dilute any evolved hydrogen to maintain a concentration below the lower flammability limit.

The vapor leaving the Cs evaporator separator vessel contains water and nitric acid and entrained salts. The salts (including Cs, K, Ca, Na, Al, and nitrate [NO_3]) dissolved in the feed are non-volatile at the Cs evaporator separator vessel operating conditions and accumulate in the bottom of the Cs evaporator separator vessel. Passing the vapor stream from the Cs evaporator separator vessel and demister, through the Cs evaporator nitric acid rectifier (CNP-DISTC-00001) increases the concentration of the recovered acid. The column operates with a high top reflux flow from the Cs evaporator primary condenser (CNP-HX-00002). Recovered acid flows from the bottom of the rectifier to the Cs evaporator recovered nitric acid vessel, CNP-VSL-00004. A conductivity probe is used to monitor the nitric acid concentration in the rectifier bottoms (i.e., recovered nitric acid solution). The recovered nitric acid collected in vessel

CNP-VSL-00004 can be sampled; this vessel is not equipped with a conductivity probe for real-time monitoring of recovered nitric acid solution acidity.

The rectifier bottoms product is predicted to be nominally 0.5 M HNO_3, and the overheads product is water (H_2O). The rectifier will have the ability to reflux 100% of the vapor received from the Cs evaporator separator vessel back to the Cs evaporator separator vessel. This allows for continuous operation of the evaporator system in a standby state when eluate is not being fed to the Cs evaporator separator vessel. This minimizes the startup and shutdown of the system when elution of a Cs IX column is not required. The rectifier is also under vacuum conditions, being coupled with the Cs evaporator separator vessel and condensers, and is sealed by a barometric leg down to the Cs evaporator recovered nitric acid vessel (CNP-VSL-00004), which has a batch capacity of 6,200 gallons.

2.3.1.3 Relationship to Other Systems

Cs eluate is transferred from the Cs IX column (CXP-IXC-00001, -00002, -00003, or -00004) to the Cs evaporator breakpot (CNPBRKPT-00002).

Recovered nitric acid eluent is transferred from the Cs evaporator recovered nitric acid vessel (CNP-VSL-00004) to the Cs IX reagent vessel (CXP-VSL-00005).

The Cs evaporator separator vessel is operated at reduced pressure to lower the boiling temperature of the liquids. The system uses a two-stage steam ejector system to create reduced pressure in the separator vessel. Exhaust vapors from the ejectors are condensed in the Cs evaporator secondary condensers (CNP-HX-00003 and CNP HX-00004) prior to venting to the ventilation system scrubbing equipment. Process condensate from the Cs evaporator primary condenser and Cs evaporator secondary condenser drains to the acidic/alkaline effluent vessels, PWD-VSL-00015 and PWD-VSL-00016, located in the PWD.

Concentrated Cs eluate solution is transferred from the Cs evaporator separator vessel (CNP-EVAP-00001) to the HLW blend vessel (HLP-VSL-00028 or HLP-VSL-00027B) via a breakpot. During discussions with WTP Engineering staff, it was noted that the Cs concentrate would be neutralized prior to transfer to the HLP.

2.3.1.4 Development History and Status

The WTP Project has conducted laboratory-scale testing to characterize actual Cs eluate solutions, prepare simulants, and conduct vacuum evaporation of simulated Cs eluate solutions. The physical and chemical properties of the Cs eluate and concentrate solutions are understood based on laboratory-scale experiments and analytical models having been developed to predict physical properties of these solutions (SCT-M0SRLE60-00-183-02). The actual Cs eluate solutions were derived from laboratory-scale IX column testing using SuperLig® 644 resin. The project has subsequently decided to use spherical resorcinol formaldehyde (RF) resin in the CXP.

The laboratory-scale components tested were surrogates for the following system components: reboiler (CNP-HX-0001), separator vessel and demister pads (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and recovered nitric acid vessel (CNP-VSL-00004). However, the laboratory-scale components tested did not include a surrogate for the acid rectifier column (CNP-DISTC-00001) present in the CNP (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B).

2.3.1.5 Relevant Environment

The relevant environment for the CNP, as identified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001), the *System Description for the Pretreatment Facility Cs Nitric Acid Recovery Process (CNP) System* (24590-PTF-3YD-CNP-00001), and as modified by the *Engineering Specification for Cesium Nitric Acid Recovery Forced Circulation Vacuum Evaporator System* (24590-PTF-3PS-MEVV-T0002, Rev. 4), is:

- The system shall concentrate Cs eluate and post-elution rinse solutions from the CXP at operating pressure of approximately 0.10 bar (1.5 psia) results in an operating temperature of 50°C to 55°C.
- The system shall operate batchwise continuously with a non-constant feed rate of 6.9 to 10 gpm at 25°C.
- The system shall produce a vapor with condensed acid concentration of approximately 0.5 M HNO_3.
- The system shall maintain a constant volume of 0.5 M HNO_3 solution, with excess nitric acid and water purged from the system.
- At steady state operation, the concentration of Cs in the evaporator bottoms shall be at least 5,000,000 times greater than that in the recovered eluent (Cs decontamination factor of 5,000,000).
- The system shall produce a concentrated Cs eluate solution with a maximum specific gravity of 1.37 g/ml (for sodium hydroxide [NaOH] at 80% of its solubility limit), which is exclusive of any solids present.
- All system components within the R5/C5 black cell (except for the demister pads) shall be non-replaceable components with a design life of 40 years. The reboiler and recirculation pump in the R5/C5 hot cell shall be remotely replaceable. The demister pads are contact maintained and replaceable.

2.3.1.6 Comparison of the Relevant Environment and the Demonstrated Environment

The CNP process and equipment technology concept has not been prototypically demonstrated in a relevant environment. The capability of the system to produce a concentrated Cs eluate solution with a maximum specific gravity of 1.37 g/ml (for sodium nitrate [$NaNO_3$] at 80% of its solubility limit) has not been demonstrated. The functions of the CNP, and in particular the rectifier column and demister pads, have not been fully demonstrated in the laboratory or a simulated environment. These issues are discussed further below.

A comparison of the CNP lab-scale testing system, CNP design as proposed by the Contractor, Hanford's B-Plant application, and Hanford's Plutonium-Uranium Extraction (PUREX) Plant application for the recovery on nitric acid is provided in Table 2.2. The information in this table illustrates that the CNP design by the Contractor:

- Modifies the historic use of the technology at Hanford, and
- Repackages the nitric acid recovery technology, into a new environment, that requires operation of the technology beyond its demonstrated capability.

Table 2.2. Comparison of Nitric Acid Evaporation Systems

System	Components and Operating Volume	Mode of Operation	Function	Operating Range	Control Concept	Other Special Requirements	Testing / Operating Basis
Lab-Scale	Evaporator vessel: 5-in. diameter; 2.2-L Two Condensers	Semi-batch using constant feed composition throughout operation	Determine relationships for solubility and physical properties for Cs eluate concentrate	Evaporator vessel initially charged with 7.5 M HNO_3 Four separate evaporator tests with feed at 0.24, 0.28, 0.29, and 0.36 M HNO_3	Vacuum used to control boiling temperature in evaporator vessel All vapors condensed	None	Testing conducted to provide information for modeling plant system
CNP Design Concept	Separator Vessel (CNP-EVAP-00001): 1,500-gallons Reboiler (CNP-HX-00001) Nitric Acid Rectifier (CNP-DISTC-00001) Two Condensers (CNP-HX-00002 and CNP-HX-00003) Recovered Nitric Acid Vessel (CNP-VSL-00004): ~6,200-gallons	Fed directly from CXP column Continuous during CXP elution cycle	Concentrate Cs eluate to 80% of solubility limit of dissolved salts Recover 0.5 M HNO_3 at high purity	Evaporator vessel initially charged with 7.2M HNO_3, but can range from 5 to 8 M HNO_3 6.9 to 10 gpm feed varies from water to 0.5 M HNO_3 during evaporator operation	Vacuum used to control boiling temperature in evaporator vessel Conductivity probe in rectifier drain line used to control rectifier operation and concentration of HNO_3 in recovered HNO_3 product	Achieve Cs decontamination factor [DF] of 5 million (must be suitable for re-use in CXP)	Limited, lab-scale tests, calculations and modeling Plan to demonstrate Cs DF during WTP PT Facility cold commissioning

Table 2.2. Comparison of Nitric Acid Evaporation Systems

System	Components and Operating Volume	Mode of Operation	Function	Operating Range	Control Concept	Other Special Requirements	Testing / Operating Basis
Previous Application							
B Plant Cell 5 (ARH-CD-691, pp. 600 – 603)	Feed vessel: 1,800 gallons Integrated Evaporator / Separator vessel: 260 gallons Condenser	Fed from 1,800-gallon vessel Continuous during Solvent Extraction processing	Concentrate Strontium nitrate solution to 0.05 to 0.2 M	Evaporator vessel initially charged with 1.0 M HNO_3. Feed adjusted to 0.3 M HNO_3 in feed vessel	Vacuum used to control boiling temperature in evaporator vessel Nitric acid recovery/re-use not intended	Condensed nitric acid solution neutralized and processed in separator evaporator along with other low-level waste solutions. Low strontium (Sr) DF (<100,000) required	Plant operations
PUREX Plant (HW-31000, pp. 1001 – 1014)	Integrated Evaporator / Separator vessel with bubble-cap tray and packed section: 3,200 gallons Condenser Bubble-cap tray absorber tower Two 30wt% HNO_3 intermediate product vessels: 5,00 gallons each Vacuum fractionator column Two 60 wt% HNO_3 product vessels: 15,00 gallons each	Semi-batch	Concentrate mixed fission product waste solution and recover HNO_3 for re-use in solvent extraction process	~1.6 M HNO_3 feed to evaporator ~4.5 M HNO_3 produced from absorber tower, which collected in intermediate product vessels and fed to vacuum fractionator	Vacuum used to control boiling temperature in evaporator vessel Two-step process to decontaminate nitric acid and produce concentrated HNO_3	Mixed fission product DF ~100,000	Plant operations

The discussions below address each of the aspects of this technology and the technical challenges that exist in the application of this technology.

Cesium Eluate Concentration/Evaporator: The Contractor has estimated that the Cs eluate solution has a maximum specific gravity of 1.37 g/ml and a corresponding $NaNO_3$ concentration of 2.6 M at 80% $NaNO_3$ saturation (24590-PTF-3PS-MEVV-T0002, Rev. 4, pg. C-1; 24590-WTP-RPT-PT-02-019, Rev. 1). The laboratory evaporator tests demonstrated at 100% $NaNO_3$ saturation, the specific gravity varied from 1.312 to 1.372 g/ml (SCT-M0SRLE60-00-183-02, Rev. 00A, pg. 13). This indicated that if the CNP were operated at a specific gravity of 1.37, then solids would form in the evaporator. The evaporator was not designed to operate with solids. During discussions with WTP Engineering staff, it was noted that the Cs concentrate would be neutralized prior to transfer to the HLP. This will result in the formation of solids from the precipitation of salts. *The Contractor should re-evaluate the specific gravity operating limit for controlling the concentrated Cs eluate to a maximum of 80% saturation and the ability of the evaporator to manage solids. If required, design changes should be specified.*

The WTP Contractor completes corrosion evaluations to support the specification of materials of construction for the WTP vessels and piping. The corrosion evaluation for the CNP-EVAP-00001 (24590-PTF-N1D-CNP-00005) indicates that the pH range for evaporator operations will be 0.3 to 14. The lower end of this pH range is based on an assumed 0.5 M HNO_3 concentration in the Cs eluate. However, the evaporator is charged with nitric acid up to 8 M. The engineering material balance (24590-WTP-MVC-V11T-00005) referenced in the corrosion evaluation correctly states the lower end of the pH range at -0.9. *The Contractor should reassess the corrosion evaluations for the CNP vessels and piping.*

Rectifier Column: Laboratory demonstration of the acid rectifier column (CNP-DISTC-00001) has not been conducted.

Rectifier (also referred to as distillation or fractionator) columns are commonly used in commercial industry to recover nitric acid and other distillates. The PUREX Plant at the Hanford Site recovered nitric acid from a vacuum evaporator system that processed mixed fission product wastes (HW-31000, pp. 1001 – 1061) during plant operations from 1956 to 1995. The PUREX Plant acid recovery system was designed for remote maintenance/replacement and operation. The CNP rectifier column is not designed for remote replacement. While the nitric acid absorption and fractionation technology is similar between PUREX and the CNP design, the equipment used in the PUREX Plant and the CNP differ significantly.

The PUREX Plant acid recovery system included a vacuum evaporator, a nitric acid absorber tower and condenser, two 30 wt% concentrated nitric acid receiver vessels, a vacuum fractionator column, and two 60 wt% concentrated nitric acid receiver vessels. The distilled nitric acid was passed through the absorber tower and condenser, which resulted in the collection of 30 wt% nitric acid in one of the two 30 wt% concentrated nitric acid receiver vessels. One of the 30 wt% concentrated nitric acid receiver vessels was used to receive 30 wt% acid from the absorber tower while the other vessel contents were feed to the fractionator column, thus providing a uniform concentration of nitric acid as the feed to fractionator column. While the PUREX Plant fractionator column is similar to the CNP rectifier column, the CNP does not include intermediate vessels to collect the nitric acid solution distilled from the separator vessel (CNP-EVP-0001).

The concentration of nitric acid in the Cs eluate solution will vary based on the composition of the waste being processed by the CXP. The CNP engineering specification used for procuring this equipment system states the nitric acid concentration in the Cs eluate will be a minimum of 0.4 M and a maximum of 0.5 M (24590-PTF-3PS-MEVV-T0002, Rev. 4, Appendix C). However, the pre-elution and

post-elution rinse sequences for the Cs IX column results in dilute (less than 0.4 M) nitric acid and water being processed in the CNP (24590-PTF-3YD-CXP-00001, Rev. 0, pp. 6-10 and 6-11). The project has prepared mass and energy balance calculations for the CNP components including the rectifier column (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B). The mass and energy balance calculations assumed the nitric acid concentration in the feed to the CNP is 0.5 M and calculated that the recovered nitric concentration is 0.57 M (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B, pp. 29-30). The mass and energy balance calculation did not evaluate feeding a lower and variable nitric acid concentration to the CNP. In addition, this variable nitric acid concentration was not estimated or included in the engineering procurement specification (24590-PTF-3PS-MEVV-T0002) for the CNP. *The functional requirements of the CNP to treat a variable Cs eluate composition while the evaporator concentration varies have not been evaluated through engineering analysis or through testing. In particular, the performance and controls of the rectifier column have not been fully demonstrated in the laboratory or a simulated environment.*

The project plans to use RF resin instead of SuperLig® 644 resin in the CXP. The project has evaluated increasing the resin contained in the Cs IX columns from 415 to 600 gallons (24590-WTP-RPT-RT-06-001, pg. 13), while still eluting the resin with 15 bed volumes (BV) of 0.5 M HNO_3. Therefore, the required volume of 0.5 M HNO_3 solution to elute an IX column is 9,000 gallons (15 BVs x 600 gallons per BV = 9,000 gallons). The batch capacity of the recovered nitric acid vessel (CNP-VSL-00004) is approximately 6,200 gallons, which is not sufficient to contain the entire volume of eluent needed to complete the elution of a 600-gallon column. Regardless of whether the project increases the volume of resin used in an IX column, the need may arise to use more than 15 BVs to completely elute an IX column. For conditions where more than 6,200 gallons of 0.5 M HNO_3 solution are required to eluate an IX column, the project plans to operate the CNP in a continuous mode: evaporating Cs eluate, recovering nitric acid solution in vessel CNP-VSL-00004, and transferring recovered nitric acid solution to the Cs IX reagent vessel (CXP-VSL-00005). Critical to the operation of the CNP coupled to the CXP is the use of an in-line conductivity probe to control the composition of the rectifier product. *This continuous mode of operation for the CNP has not been demonstrated in the laboratory or in a simulated environment. In particular, the performance and controls of the rectifier column has not been fully demonstrated in the laboratory or a simulated environment.*

As part of the Contractor's Pretreatment Reconfiguration studies in 2001, two CNP eluate (CNP feed) receipt vessels with a volume of 10,000 gallons each and two eluant (CNP acid product) vessels with a volume of 9,000 gallons each were removed from the conceptual design provided by DOE (CCN:020148). Preserving these vessels in the CNP flowsheet would have allowed operation of the CNP to have been decoupled from the CXP, and likely simplified process operations and control.

Demister Pads: The demister pads remove entrained droplets from the vapor phase leaving the evaporator vessel and in combination with the rectifier column are intended to achieve the design basis Cs decontamination factor of 5,000,000 (concentration of Cs in the evaporator bottoms relative to the recovered nitric acid solution). The demister pads are located in the top of the separator vessel, which includes sprays to wash the pads during normal operation and for maintenance. Hands-on maintenance is planned for replacement of the demister pads. The ability to adequately decontaminate the demister pads for hands-on replacement has not been demonstrated in previous DOE radiochemical processing plant operations. The basis for the proposed contact (e.g., hands-on) changeout of the CNP separator vessel demister pads has not been established from experimentation or analysis.

The Cs concentration was not measured in the recovered nitric acid solution from laboratory simulations of the evaporator system. Additionally, the vapor flux rate in the laboratory simulations of the evaporator system was not prototypic of that for the CNP (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B). *The functionality of the*

CNP has not been demonstrated to achieve a Cs decontamination factor of 5,000,000 for concentration of Cs in the evaporator bottoms relative to the recovered nitric acid solution.

2.3.1.7 Technology Readiness Level Determination

The CNP was determined to be a TRL 3 because laboratory-scale testing has only simulated the reboiler, separator vessel, and condenser components of the system; the demister pads and rectifier column were not simulated. Simulation of the CNP components has not included the full composition range of feed solutions to the evaporator (reboiler and separator vessel) from the CNP. Proposed changes to the CNP including the neutralization of the Cs concentrate product and impacts of the change to the use of RF resin have not been evaluated.

A subcontractor is completing the detailed design and fabrication of the evaporator components for the CNP: reboiler (CNP-HX-0001); separator vessel and demister pads (CNP-EVP-0001); condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004); rectifier column (CNP-DISTC-00001); steam condensate skid; and associated instrumentation, pumps and ejectors. The Cs evaporator breakpot (CNPBRKPT-00002), recovered nitric acid vessel (CNP-VSL-00004), and the eluate contingency storage vessel (CNP-VSL-00003) are being separately designed and procured. The WTP Contractor is independently developing the software to control this system. The subcontractor is required to conduct a functional test of the evaporator equipment and skids (24590-PTF-3PS-MEVV-T0002, Rev. 4, Section 7.1.4). The subcontractor is also required to demonstrate removal of the demister pad (24590-PTF-3PS-MEVV-T0002, Rev. 4, Section 7.1.5); however, demonstrating installation of a new demister pad is not required. The project is relying upon the verification of the design concept and in particular the Cs decontamination factor after installation in the PT Facility and during cold commissioning (24590-PTF-3PS-MEVV-T0002, Rev. 4, Section 7.2). Modification of the system during or after commissioning would be expensive and time-consuming and could result in delays to hot commissioning.

Because of the risks associated with CNP technology, it is recommended that:

Recommendation 1

Design activities associated with the CNP should be discontinued until: (1) a reassessment of the design and operational requirements for the CNP is completed; (2) the engineering specification for the CNP is revised to reflect operational conditions; and (3) the technology concept, which includes the process equipment and control system, is demonstrated through integrated prototypic testing.

Recommendation 2

The CNP should be functionally tested prior to installation in the black cell. The testing should include: testing with representative process feed compositions; verifying the process control system concept; verifying the ability to control and monitor the composition of the nitric acid product; demonstrating the cesium decontamination factor of 5 million; and demonstrating the ability to adequately decontaminate the demister pads using the sprays installed in the separator vessel.

Supporting Recommendations

- The specific gravity operating limit for controlling the concentrated Cs eluate in the CNP separator to a maximum of 80% saturation should be re-evaluated. Based on the WTP Contractor's plan to neutralize Cs concentrate in the separator, and thereby create solids, this operating constraint may not be required.

- The engineering specification for the CNP should be modified to include (1) the estimated variable feed composition and (2) factory acceptance testing to demonstrate removal and installation of the demister pads from the separator vessel.
- The Contractor should reassess the corrosion evaluations for the CNP vessels and piping based the operating conditions of the system.

2.3.2 Cesium Ion Exchange Process System (CXP)

2.3.2.1 Function of the CXP

The primary functions of the CXP are to receive ultrafiltration permeate from the Ultrafiltration Process System (UFP), remove Cs from the UFP permeate using IX, transfer the Cs-treated LAW (e.g., eluate) to the Treated LAW Evaporation Process System (TLP), and maintain hydrogen to a concentration below the lower flammability limit. Because the IX media has a limited capacity for Cs, the CXP must also perform IX media elution and regeneration, as well as spent media removal and fresh media addition. The Cs eluate from IX media elution is transferred to the CNP, as discussed in Section 2.3.1.

2.3.2.2 Description of the CXP

The CXP is described in the *System Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001). A block flow diagram of the CXP is provided in Figure 2.2. The nitrogen inerting collection piping to vent hydrogen (and other gases) from the Cs IX columns has been modified since issuance of the CXP system description, as described in *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i, Section 3.4.1.8.4).

The CXP utilizes four IX columns (CXP-IXC-00001, -00002, -00003, and -00004) to separate Cs from the UFP permeate. Three columns in series are in service while one is in standby mode. The UFP permeate is transferred from the Cs IX feed vessel (CXP-VSL-00001) through heat exchangers into three IX columns that are operated in series. The first column is designated as the lead column. The second column is designated as the lag column. The third column is designated as the polishing column. Cs is exchanged with sodium (Na) ions on the IX resin as the UFP permeate passes through the three IX columns. The Cs depleted solution exiting the polishing column is referred to as Cs treated LAW, which is collected in one of three vessels (CXP-VSL-00026 A/B/C).

At some point in processing, the removal efficiency of the lead column is reduced. Eventually, the Cs concentration in the effluent streams exiting the columns will increase to a level approaching the predetermined maximum. The point at which the Cs concentration in the effluent from the IX column reaches a predetermined maximum (which is relative to the sodium concentration) is called the breakthrough point. The Cs-137 monitors located on the effluent from each column will determine when the Cs concentration in one of the effluents reaches its setpoint. When this breakthrough point is reached, the valving will be changed so that the freshly regenerated column is placed in the polishing position and the column previously in the lead position is valved off for elution and regeneration. The column previously in the lag position is now the lead column, and the polishing column is now the lag column.

The column previously in the lead position is flushed with 0.1 M NaOH (dilute caustic) solution (from vessel CXP-VSL-00004) and rinsed with demineralized water. The solution displaced from the column during the dilute caustic flush is collected in one of the three Cs-treated LAW collection vessels (CXP-VSL-00026 A/B/C). The rinse water passes through the column to one of the acidic/alkaline effluent vessels (PWD-VSL-00015 or -00016). Nominally, 0.5 M HNO_3 at 25°C from the Cs evaporator

recovered nitric acid vessel (CNP-VSL-00004) is used to elute Cs (and other cations) from the column. The eluent passes through the column to the Cs evaporator separator vessel (CNP-EVAP-00001) via breakpot CNP-BRKPT-00002. Following completion of the elution step, nitric acid is displaced from the column to the Cs evaporator separator vessel using demineralized water. Then, the column is regenerated using six BVs (a BV is the volume of resin in the column) of 0.25 M NaOH solution. The first three BVs of caustic solution are routed to the acidic/alkaline effluent vessels (PWD-VSL-00015 or -00016). The remaining three BVs are routed to the Cs IX caustic rinse collection vessel (CXP-VSL-00004).

After elution and regeneration, the column will be in standby until it can be returned to the train as the polishing column. LAW, eluant, other reagent solutions, and rinses are transferred into the column via the Cs IX reagent vessel (CXP-VSL-00005), and enter the column through the top distributor.

After several loading, elution, and regeneration cycles, the resin is expected to lose performance and is termed “spent.” The spent IX resin is slurried with recycled IX resin flush solution (primarily water), flushed out of the column, and collected in the spent resin slurry vessels (RDP-VSL-00002-A, -B, or -C), which are part of the Spent Resin Collection/Dewatering Process System (RDP). Fresh resin from the Cesium Resin Addition Process System (CRP) is slurry fed by gravity from the Cs resin addition air gap vessel (CRP-VSL-00002) to the appropriate column.

Hydrogen gas is produced in the Cs IX columns due to radiolytic decay of the resin and LAW solution in the Cs IX column. Soluble hydrogen and any hydrogen bubbles produced due to solution saturation are normally be expected to be entrained and swept out of the Cs IX column in the flowing liquid stream. There is concern that the velocity of rising hydrogen bubble may exceed the velocity of liquid downflow through the Cs IX column. In this case, hydrogen would accumulate in the Cs IX column, where it would be collected in the nitrogen inerting collection piping. The nitrogen inerting collection piping uses four level control sensors to automatically regulate the liquid and nitrogen gas volumes in the piping and vent gases to the process vessel ventilation system via a vented breakpot (24590-WTP-SED-ENS-03-002-02, Rev. 1i, pg. 3.4.1.8.12).

2.3.2.3 Relationship to Other Systems

UFP permeate solution is transferred from the three UFP permeate vessels (UFP-VSL-00062A, -B, -C) to the Cs IX feed vessel (CXP-VSL-00001).

Three collection vessels (CXP-VSL-00026 A/B/C), each with a batch volume of 26,000 gallons, receive the Cs treated LAW solution.

The Cs eluate solution is sent to the Cs evaporator separator vessel (CNP-EVAP-00001) via breakpot CNP-BRKPT-00002 in the CNP for further processing to recover the nitric acid eluent and concentrate the Cs product.

Post-loading step water rinse and dilute NaOH regeneration solution are transferred to the acidic/alkaline effluent vessels (PWD-VSL-00015 or -00016).

Fresh resin is slurried and fed by gravity from the Cs resin addition air gap vessel (CRP-VSL-00002) in the CRP to the appropriate column. Spent resin is extracted from a column to the spent resin slurry vessels (RDP-VSL-00002-A, -B, or -C), which as part of the RDP.

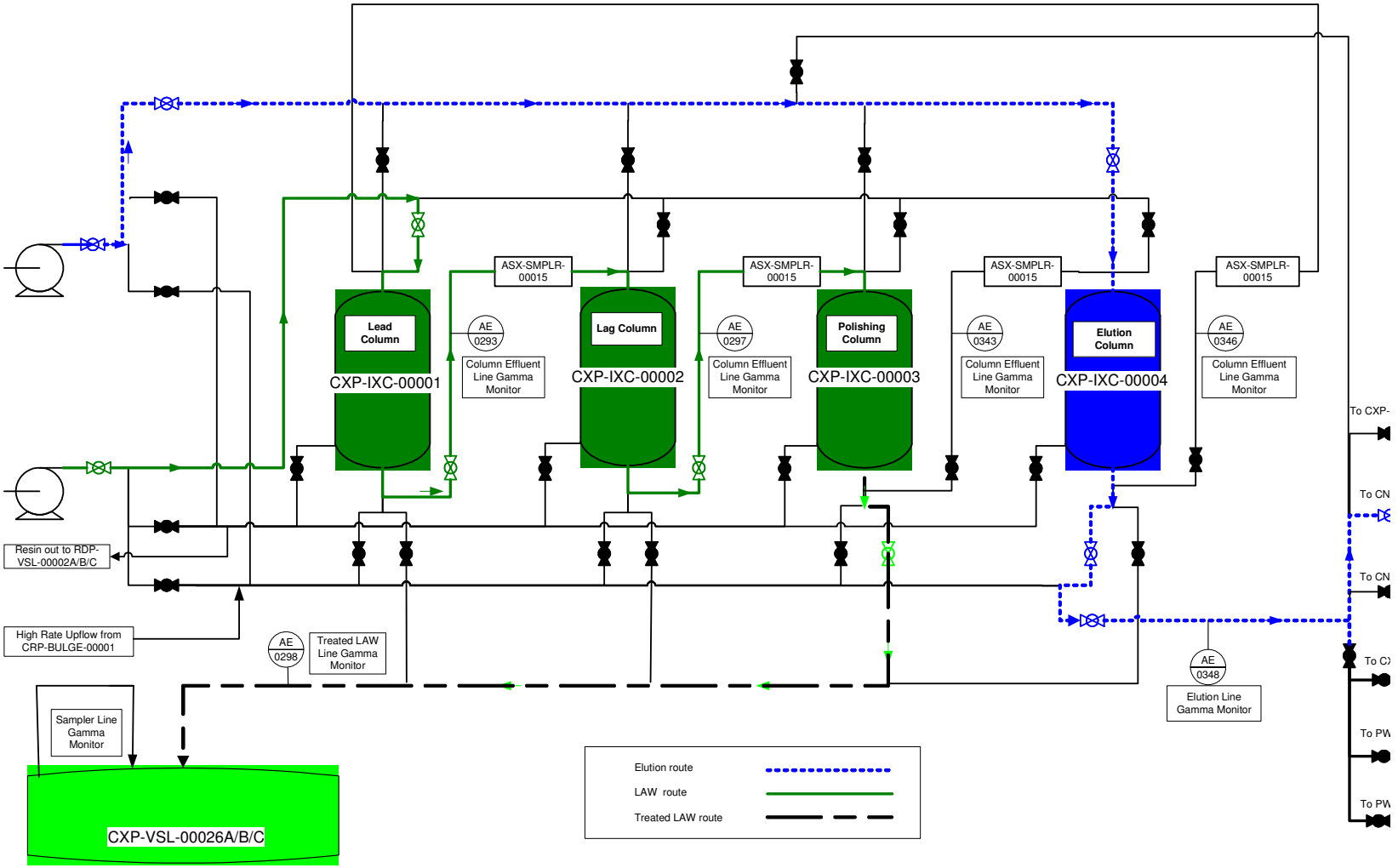

Figure 2.2. Block Flow Diagram for the Cesium Ion Exchange Process System

2.3.2.4 Development History and Status

The WTP Project has conducted laboratory-scale testing of the Cs IX process using radioactive waste samples and simulants. Early testing was conducted using SuperLig® 644 resin, while later testing used an alternative resin, spherical RF. A summary of the status of development for both IX materials is provided in *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644®* (24590-WTP-RPT-RT-06-001). Since the project is planning to use spherical RF resin, this assessment addresses only spherical RF resin in the CXP.

The physical properties of spherical RF resin and the chemical and radiological degradation mechanisms have been determined through laboratory testing in a relevant environment (SCT-MOSRL60-00-221-00001, Rev. 00A; 24590-WTP-RPT-RT-06-001, Sections 5.3 and 5.4). Hydraulic testing of scaled columns using flow rates representative of planned CXP operating conditions was conducted to determine bed flow permeability, pressure drop and fluidization velocity for spherical RF resin (24590-WTP-RPT-RT-06-001, Section 4). Testing of spherical RF resin degradation during storage is ongoing and is expected to be complete by September 2007 (24590-WTP-RPT-RT-06-001, Section 5.2). Gas generation and resin nitration from radiation and chemical (nitric acid [HNO_3] and permanganate [MnO_4]) exposure of spherical RF resin has been determined (24590-WTP-RPT-RT-06-001, Section 8).

The project has demonstrated manufacturing scale-up and reproducibility of spherical RF resin (24590-WTP-RPT-RT-06-001, Section 8.5). Six 100-gallon batches of spherical RF resin were manufactured by two different vendors. These batches of resin were tested and shown to have acceptable mean particle diameter, density, and Cs capacity.

The project has conducted laboratory scale testing of IX columns containing spherical RF resin using AP-101 (SCT-M0SRLE60-00-110-00029, Rev. 00A), AZ-102 (24590-101-TSA-W000-0004-99-00013, Rev. 00A), AN-105 (24590-101-TSA-W000-0004-91-00003, Rev. 00A), and AN-107 (SCT-M0SRLE60-00-110-00029, Rev. 00A) simulants and actual tank AP-101 and pretreated AN-102 (24590-101-TSA-W000-0004-1742-00001, Rev. 00A) waste samples. These laboratory-scale column tests were conducted using flow rates, operating modes, and temperatures that mimic the planned CXP operating conditions. The simulants used in these tests contained simple organic compounds (i.e., oxalate, glycolic acid, acetate, and formate), but did not contain anti-foaming agent (used in various PT Facility systems) or other organic compounds (e.g., chelating agents, tri-butyl phosphate [TBP], and normal paraffin hydrocarbon [NPH]) known to be present in Hanford Site tank wastes. The project plans to use data from these tests to update by September 2007 a computer model for the spherical RF resin IX system (SCT-M0SRLE60-00-05-00003, Rev. 00A).

2.3.2.5 Relevant Environment

The relevant environment for the CXP, as identified in the *Basis of Design* (24590-WTP-DB-ENG-01-001), the *System Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001), and as modified by the *Engineering Specification for the Cesium Ion Exchange Columns* (2459O-PTF-3PS-MWDO-TOOO5, Rev. 1), is:

- The CXP shall remove Cs-137 from the ultrafiltration system permeate to allow for production of an immobilized low-activity waste (ILAW) form that meets contract specifications and facilitate the maintenance concept established for the ILAW melter system.
- The CXP shall process ultrafiltration permeate at a volumetric flow rate between 5 to 22 gpm. *(Note the Contractor is evaluating an increase in the flow rate to 30 gpm).*

- The CXP time cycle for the LAW loading and feed solution displacement processing steps shall exceed the combined time cycle for the elution, post-elution rinse, and regeneration processing steps in order to support continuous semi-batch mode processing of LAW solution.
- The CXP shall be capable of removing greater than 99% by volume of resin from the IX columns upon completion of the resin removal mode using a maximum volume of 7,500 gallons of water to displace the resin.
- The IX columns shall be designed for 10-year life and remote removal and replacement using remote jumper techniques, closed-caption television (CCTV), hot cell crane, and crane-mounted impact wrench.

2.3.2.6 Comparison of the Relevant Environment and the Demonstrated Environment

The chemistry and physical properties of the spherical RF resin has been demonstrated in laboratory- and pilot-scale tests with similar process conditions and in a relevant environment. However, the project has not completed all planned testing of spherical RF resin. Ongoing planned testing includes resin degradation during storage, spent resin analysis after contacting with high concentrations of organic compounds and metals (needed for spent resin disposal evaluation), and update of the IX process computer model. These tasks are scheduled to be completed by September 2007 (24590-WTP-RPT-RT-06-001, Section 9).

Physical degradation testing, such as osmotic shock and crushing, for irradiated, spherical RF resin samples was not conducted (SCT-MOSRLE60-00-10-00005, Rev. 00A, pg. 4). The project has not evaluated the effect of anti-foaming agent and separable organics (such as tri-butyl phosphate [TBP]) present in the feed on the CXP. Evaluation of the effect of separable organics on the CXP is required by the WTP Contract, Standard 2, "Research, Technology, and Modeling," item (3) (viii), "Effect of Separable Organics" (Contract No. DE-AC27-01RV14136).

The project has not demonstrated the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns. The PT Facility Safety Envelope Document states "For flammable gas to exceed the nitrogen inerting gas volume within the Cs IX column collection piping, a loss of the level control would be required. A loss of level control would require failure of the credited CXP collection piping liquid low-low level LS-4 sensor. The functionality of the CXP collection piping liquid low-low LS-4 sensor (which is not required to meet the single failure criterion in accordance with the revised safety criteria defined in the SRD) will be verified" (24590-WTP-SED-ENS-03-002-02, Rev. 1i, pg. 3.4.1.8.12). The Assessment Team found no evidence of verification of the functionality of these liquid level sensors.

Hydraulic testing of spherical RF resin was conducted using relevant process conditions (e.g., superficial velocity and flow direction), but did not use a prototypic IX column; the column internals such as resin retention screen and flow distributor were not prototypic of the current design. Therefore, the capability was not demonstrated to remove greater than 99% by volume of the resin from the column. The project has prepared a specification for a vendor to prepare the detailed design and fabrication of the IX columns (24590-PTF-3PS-MWD0-T0005, Rev. 1). Although this specification requires the columns to be designed to achieve greater than 99% by volume removal of resin from the IX columns upon completion of the resin removal mode, no factory testing is required to demonstrate compliance with this requirement.

The WTP contractor recognizes that the engineering specification (24590-PTF-3PS-MWD0-T0005, Rev. 1) for the IX columns needs to be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the External Flowsheet Review Team (EFRT) recommendations for the CXP. The project plans to update this specification before resuming procurement of the IX columns (24590-WTP-PL-ENG-06-0026, Rev. 000).

The consequences of solids in the feed stream to the IX columns are not understood. Almost all testing performed to date with the new "mono-sized" (i.e., narrow resin partial size distribution) spherical RF resin has been performed with feeds free of solids. It is expected that the spherical RF resin paths for any solids to pass by the resin, greatly reduce the risk of plugging the column. Issues with the possible negative impacts of solids present in the CXP feed as identified by the WTP Contractor include:

- Column or areas in the column becoming plugged with solids.
- Solids remaining on the resin, depending on solids makeup, may not be easily dissolved.
- Cs may be occluded into the precipitating solid matrix that becomes a carrier for Cs bypassing resin.
- Precipitating solids coating resin IX sites preventing ion exchange from occurring, resulting in early Cs breakthrough.

Recent analysis of the PT Facility flowsheet (24590-WTP-RPT-PO-07-002) estimates the concentration of solids (gibbsite and sodium oxalate) in the stream entering the Cs IX columns and indicates that undissolved solids are almost always present. Concentrations range from up to 7,000 ppm, assuming that sludge leaching occurs in the UFP-VSL-00002A/2B vessels, to approximately 800 ppm, assuming that sludge leaching occurs in the UFP-VSL-00001A/1B. Additional results provided in these analyses are:

- For caustic leached in UFP-VSL-00002A/B, about 4% of the aluminum entering the CXP feed system precipitated, and about 75% of the solids, are sodium oxalate; about 25% of the solids are gibbsite.
- For caustic leaching in UFP-VSL-00001A/B, about 2% of the aluminum entering the CXP feed system precipitated, and about 1% of the solids, are sodium oxalate; about 99% of the solids are gibbsite.

Based on these results of the flowsheet study (24590-WTP-RPT-PO-07-002), the WTP Contractor recommended the following:

- Additional studies be performed using the preferred CXP resin to determine column performance and operating issues with CXP feeds that contain freshly precipitated sodium oxalate and gibbsite solids. The study must be comprehensive enough to determine CXP feed limits for sodium oxalate solids and gibbsite solids.
- Additional research be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate. It is also important to understand the morphology of freshly precipitated sodium oxalate.
- An engineering assessment be undertaken to determine how to accomplish mixing in CXP-VSL-00001. This vessel has no provisions for blending solutions or suspending solids. However, flowsheet modeling indicates that solids are likely to precipitate if chemical adjustments are not made to the vessel.
- Capability to add NaOH and process condensate to the Cs IX feed vessel, CXP-VSL-00001, should be added. If it becomes necessary to reduce the solids concentration in Cs IX feed, then the capability will be available.

A previous analyses by BNI (24590-WTP-RPT-PR-01-006), which was reviewed by DOE in 2005 (06-WED-009), identified the post-filtration precipitation of solids in the CXP feed as a process issue.

2.3.2.7 Technology Readiness Level Determination

The CXP was determined to be a TRL 5 due to incomplete demonstration of the process and equipment technology for the CXP and the incomplete testing/documentation of spherical RF resin. The project has not demonstrated the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns. The project has not demonstrated the capability to remove 99% by volume of the spherical RF resin from a prototypic IX column. Delaying testing of these design features until cold commissioning of the PT Facility would result in potentially expensive and time-consuming delays to hot commissioning.

Flowsheet analysis indicates that solids will always be present in the Cs IX column feed. The data on the impact of these solids on the operation of the Cs IX columns does not exist. Complete understanding of the chemical stability of the CXP feed does not exist. The equipment capability of the CXP to manage feeds containing solids does not exist.

The EFRT identified issues for the stability of the baseline IX material (SuperLig® 644), column design expertise, inadequate process development, complexity of process valving, cross contamination potential, and effectiveness of the Cs-137 breakthrough monitors. The project is addressing these issues through issue response plans (IRP) with closure of these issues anticipated by September 2007 (24590-WTP-PL-ENG-06-0026, Rev. 000). The adequacy of these IRPs was not evaluated as part of this assessment.

Because of the risks associated with the CXP, it is recommended that:

Recommendation 3

Prototypic equipment testing should be completed prior to continuing design of the hydrogen venting subsystem (nitrogen inerting and hydrogen gas collection piping system, and control system) for removing hydrogen and other gases from the cesium IX columns to demonstrate this design feature over the range of anticipated operating conditions.

> *Alternatively, the project should consider re-designing (and testing) the hydrogen venting subsystem for the IX columns in order to simplify the system. For example, a small recycle stream from the IX columns to the feed vessel (CXP-VSL-00001) could be used to vent gases from the columns. The recycle stream could be controlled through the use of orifice plates and stop valves for isolation.*

Recommendation 4

The adequacy of the design concept for CXP-VSL-00001 should be reevaluated and a determination made if this vessel should be modified to include mixing, chemical addition, and heating/cooling to mitigate anticipated process flowsheet issues with precipitation of solids in the CXP feeds.

Supporting Recommendations

- Testing of spherical RF resin should be conducted to: (1) assess physical degradation for irradiated resin samples; (2) assess effects from anti-foaming agent and separate organics present in the feed to the CXP; and (3) assess the impact of particulates on IX column performance.
- All currently planned testing and documentation of test results for spherical RF resin should be completed. (*Note: This planned work is in the WTP Baseline.*)

- Additional research should be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate.
- The engineering specification for the IX columns should be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the EFRT recommendations for the CXP.
- The engineering specification for the CXP should be modified to include factory acceptance testing of the IX column to demonstrate that the system is capable of removing greater than 99% by volume of resin from the IX column, upon completion of the resin removal mode, using a maximum volume of 7,500 gallons of water to displace the resin.

2.3.3 Treated LAW Feed Evaporation Process System (TLP)

2.3.3.1 Function of the TLP

The primary function of the TLP is to minimize the volume of water that must be processed in the LAW melter. The treated LAW feed is mixed with the scrub solution recycled from the LAW offgas treatment system just before it enters the evaporator.

2.3.3.2 Description of the TLP

The TLP is described in the *System Description for Treated LAW Process*, (24590-PTF-3YD-TLP-00001). The TLP evaporator's purpose is to increase the treated LAW concentration up to the solids crystallization point (expected range from 8 to 10 M Na) such that the vitrification efficiency is maximized without solids buildup in transfer lines. A single evaporator train in the TLP is employed to fulfill all concentration requirements. Some suspended solids are anticipated in the recycle streams to the TLP evaporator.

The WTP TLP evaporator is based on the design concept of the Hanford's 242-A Evaporator (Van Der Cook and Ogren 1976) and is a continuous, forced-circulation, vacuum evaporation system. The major components of the TLP include:

- Feed pumps
- Reboiler
- Vapor liquid separator
- Recirculation pump and pipe loop
- Slurry product pump
- Primary condenser
- Jet vacuum system
- Vessel vent system
- Condensate collection vessel

The waste processing operations in the TLP differs from the 242-A Evaporator in that the TLP is not intended to concentrate to achieve dissolved solids saturation (i.e., crystallization).

The TLP is used to concentrate treated LAW prior to transfer to LAW vitrification and reduce LAW submerged bed scrubber (SBS) condensate recycles. The concentrated LAW product is sent to the treated LAW concentrate storage vessel (TCP-VSL-00001), which stores the concentrate pending its transfer to the LAW Vitrification Facility. The LAW SBS receipt vessels are designed to operate sequentially to

maintain continuous operation of the TLP evaporator. One vessel is available for receipt, sampling, and any adjustments (i.e., pH), while the second vessel is discharging to the separator vessel.

A simplified flow diagram of the TLP is provided in Figure 2.3.

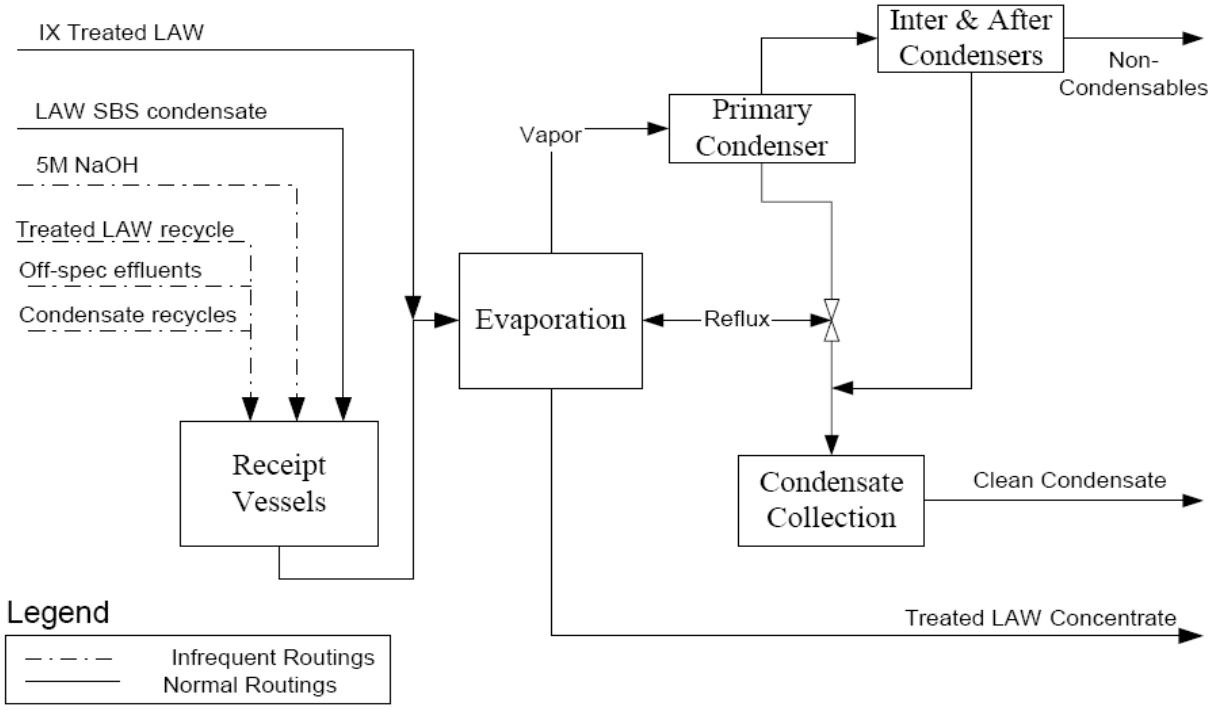

Figure 2.3. Treated LAW Feed Evaporation Process System Simplified Flow Diagram

The LAW SBS receipt vessels require continuous mixing to maintain solid suspension, for chemical blending, and homogeneity of vessel contents before sampling. The mixing is dependant on the liquid level in the vessel. The pulse jet mixers (PJM) will turn on when the vessel level is above the PJM setpoint, and turn off when the vessel level is below the PJM setpoint. The PJM setpoint is determined by the submergence requirements of the mixers (to be determined).

The recirculation pump moves the liquor through the evaporator recirculation loop maintaining a high flow rate through the reboiler. Low-pressure steam, modulated via a flow controller, is used to heat the feed liquor to the selected system boil-off rate. Low-pressure steam is available at 40 psig and 286°F (24590-WTP-DB-ENG-01-001). The heated waste is then discharged to the TLP separator vessel.

The vapors from each separator vessel are sent to a dedicated overhead system that is comprised of primary condensers, vacuum ejectors, intercondenser, aftercondenser, and demisters. Water vapor generated by evaporation of waste is condensed in the primary condenser. The ejector uses steam to discharge the noncondensable gases to the aftercondenser, where the steam condenses. The vessel vent system draws noncondensable gases from the aftercondenser through the demister to remove any liquid

entrained in the noncondensable gases. Liquids from each of these unit operations drain to the condensate vessel, where condensate vessel routing valves enable transfer to the RLD.

High-maintenance equipment exposed to highly contaminated fluids (reboilers, recirculation pumps, concentrate transfer pumps, and feed pumps) are located in a hot cell, and the equipment must be remotely maintained. The waste feed evaporator feed vessels (FEP-VSL-00017 A/B) and the separator vessels (excluding de-entrainment section) (FEP-SEP-00001 A/B) are located in a black cell. The condensers, vacuum ejectors, and condensate collection vessel are contact maintained. The TLP separator vessel has a removable plug to allow access to, and contact replacement of, the demister assembly.

The TLP has a design capacity of greater than 30 gpm. The nominal operating pressure of the evaporator is approximately 1 psia (~27.7 inches water) and the nominal operating temperature is 122°F (50°C).

2.3.3.3 Relationship to Other Systems

The two LAW SBS condensate receipt vessels (TLP-VSL-00009A/B), each with a batch volume of 80,000 gallons, receive LAW SBS vitrification effluent and effluents recycled from pretreatment. These streams include the following:

- LAW SBS condensate from the vitrification SBS condensate vessel (RLD-VSL-00005)
- Off-spec effluent from the process condensate vessels (RLD-VSL-00006A/B)
- Off-spec effluent from the alkaline effluent vessels (RLD-VSL-00017A/B)
- Treated LAW concentrate recycle from the treated LAW concentrate storage vessel (TCP-VSL-00001)
- Treated LAW input from IX vessels (CXP-VSL-00026A/B/C), which is fed directly into the recirculation loop of the evaporator system
- Off-spec effluents from radioactive liquid disposal/recycle vessels (RLD-VSL-00006A/B and RLD-VSL-00017A/B).
- Concentrated fluids from the TLP separator vessel sent to the treated LAW concentrate storage vessel (TCP-VSL-00001).

2.3.3.4 Development History and Status

The WTP *Research and Technology Plan* (24590-WTP-PL-RT-01-002) for testing of the TLP evaporator concept was aimed at addressing nine issues, stated below:

- Evaluate the ability of the TLP to meet design basis operating and throughput requirements.
- Evaluate the affect of trace organics on the evaporator operations.
- Determine the operating impacts from recycle streams.
- Determine the offgas compositions for regulatory purposes.
- Demonstrate process scale-up.
- Evaluate waste foaming in the evaporator.
- Evaluate alumino-silicate plate-out in the evaporator.
- Evaluate if SBS condensate returns produce uranium precipitates.
- Evaluate if dimethyl mercury forms in evaporator operations.

Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001). The results of the technology testing program are briefly described.

Evaluate the Affects of Trace Organics on Evaporator Operations: Separable organics, such as TBP and NPH may impact evaporator operations and thereby impact the propensity of the evaporator to foam. Therefore, testing was completed to examine to impacts of TBP/NPH on the anti-foam agent (WSRC-TR-2003-00216). Concentration levels of up to 10,000 ppm of 50% TBP/50% NPH were tested with simulated feeds with no significant increase in foaminess observed. The presence of TBP/NPH in the TLP is considered unlikely because ultrafiltration studies completed in the Semi-Integrated Pilot Plant (SIPP) showed that the filters would only allow the passage of soluble TBP/NPH. The solubility limit of TBP/NPH is < 1 ppm. Thus, no significant concentrations of TBP/NPH are expected to be processing in the TLP.

Impacts from Process Recycle Streams: Condensate from the LAW Vitrification Facility SBS is recycled into the TLP. Several tests were conducted at lab- and pilot-scale to evaluate the impact of process recycle streams.

The evaporator test program is summarized in the *Final Report: RPP-WTP Semi-Integrated Pilot Plant* (WSRC-TR-2005-00105). Glass production testing has indicated that target endpoints for the treated feed must vary depending on the waste envelope being treated. This variation in endpoint concentration requirement affects the amount of offgas scrub solution recycled back to the evaporator—the higher the concentration, the lower the recycle quantity. The ability of the system to accommodate variations in waste envelopes was examined and found to be adaptable to the system requirements.

Determine the Offgas Compositions for Regulatory Purposes: Testing was completed to characterize the partitioning of volatile and semi-volatile organic across the evaporator and confirm that the evaporator effectively destroyed or recovered the organic materials. Prior to the initiation of pilot-scale evaporator tests, 54 10-ml ampoules, each containing 0.1 gram total of a variety of organic compounds were added to the 100 gallons in the evaporator pot. After the initial charge, the same type of organics in the 10-ml ampoules was added to every 10 gallons of feed. During the operational period, liquid and offgas samples were obtained and analyzed, with liquid samples taken from the feed, concentrate, and primary and secondary condensates. Offgas samples were taken coming off the primary condenser using U.S. Environmental Protection Agency method 0010. Details of how the spiked organics partitioned across the evaporator are reported in WSRC-TR-2003-00561, *WTP Pilot Scale Evaporation Tests*.

Meet Design Basis Operating and Throughput Requirements/Demonstrate Process Scale-Up: Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76 scale in terms of cross-sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system was operated at conditions comparable to the actual process at ~ 1 psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40° to 60°C).

The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.

Waste Foaming: Control of foaming was one of the first issues recognized in the evaporation technology development program. Foam can create two operational problems: (1) Foam can expand throughout the separation volume of the evaporator and carry particulate into the mist eliminator thereby creating a

potential plug; and (2) Foam carrying liquid and solids into the demister section can cause carry-over into the offgas system that could require rework of the evaporator overhead stream.

Waste foaming was observed in the evaporator system that was integrated in the RPP-WTP SIPP (WSRC-TR-2005-00105) and has been observed in the Hanford 242-A Evaporator. The 242-A Evaporator uses DOW Chemical 1520 US anti-foam reagent (WSRC-TR-2000-00469). This reagent and several other anti-foam reagents including Q2-3138A were evaluated in the SIPP, and a recommendation to use DOW Q2-3138A was made for both the TLP and FEP evaporation systems.

Sodium Alumino-Silicate (NAS) Plate-Out in the Evaporator: Tests indicated that NAS is present in the waste and will be present in the evaporator concentrate streams. Other compounds that precipitate can be as troublesome as NAS. The formation of solids in the pilot-scale evaporator was examined due to concerns with line plugging and scaling of the heat transfer tubes. Scaling of the evaporator tubes was not found to be significant during the operation of the pilot-scale evaporator. However, during a second 100-hour test, a concentrate loop became plugged. The plug material resembled bayerite, kograrkite, natrophosphate, nitratine, thermonatrite, trona, and lithium aluminum carbonate hydroxide hydrate. The plug did not contain any NAS. The plug was attributed to a low velocity/dead zone. The line was reconfigured and no additional pluggage occurred.

Evaluate Impact of Uranium Precipitates: The operation of the 2H evaporator at the Savannah River Site (SRS) was curtailed due to the accumulation of NAS deposits that contained sodium diuranate ($Na_2U_2O_7 \cdot 6H_2O$) (containing uranium [U]-235) on the heat transfer surfaces. In the WTP, LAW SBS condensate returns, which also contain NAS, could mix in the TLP evaporator to produce similar deposits potentially leading to a criticality event. Thermodynamic modeling of the TLP evaporator was conducted to determine the likelihood of precipitation. Confirmatory laboratory tests with simulants were also conducted and a criticality safety evaluation was completed to resolve this issue. The criticality evaluation has not been evaluated by the DOE.

The criticality analysis showed that a similar event due to the build up of U-235 in the FEP evaporator is extremely unlikely.

Dimethyl Mercury Formation: The formation of dimethyl mercury is not expected at the operating temperatures of the TLP evaporator. However, the use of anti-foam in the TLP evaporator at temperatures greater that 50°C can lead to the formation of diethyl mercury if mercury is also present.

2.3.3.5 Relevant Environment

The operating environment for the TLP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001) and the TLP system description (24590-PTF-3YD-TLP-00001). The relevant operational environment for the TLP is:

- Receive and concentrate a process stream comprised of treated LAW from the CXP and SBS recycle from the LAW Vitrification Facility.
- Concentrate a high solids stream at approximately 1 psia pressure and a boiling temperature (40 to 60°C).
- Transfer evaporator concentrate at 8 to 10 M Na.

2.3.3.6 Comparison of the Relevant Environment and the Demonstrated Environment

The TLP evaporator system is based on existent, proven designs, and demonstrated in a relevant environment in SIPP testing. Operation of the PJMs in the supporting evaporator feed vessels TLP-VSL-00009A/9B has not been demonstrated. Testing and analysis is planned to verify the mixing performance of these vessels.

The technology requirements for the supporting vessel, TCP-VSL-00001, used to store concentrated LAW may not meet functional requirements to effectively mix solids generated from precipitation reactions in the filtered and concentrated LAW. The precipitation of carbonates in this waste stream was identified in 2005 by the Contactor (24590-WTP-RPT-PO-05-009).

2.3.3.7 Technology Readiness Level Determination

The TLP was determined to be TRL 4 because vessels in the TLP (TLP-VSL-00009A/9B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the TLP, is determined to be immature (e.g., TRL 4) until mixing issues on the PJMs are resolved.

The TLP evaporator design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site and is based on extensive lab-scale and pilot-scale prototypic testing completed to demonstrate this technology. The TLP evaporator is a mature technology. Technology issues evaluated included: design scale-up, effect of organics and recycle streams on process chemistry, testing and identification of an anti-foaming agent, evaluation of the plate out of salts of aluminum and uranium salts on heat transfer surfaces, characterization of offgas effluents, and evaluation of the potential to form dimethyl mercury.

2.3.4 Waste Feed Evaporation Process System (FEP)

2.3.4.1 Function of the FEP

The purpose of the FEP is to receive, blend, and concentrate waste feed and plant recycles. The FEP includes feed vessels, reboilers, separator vessels, and condensers for waste feed evaporation.

2.3.4.2 Description of the FEP

The FEP is described in the *Systems Description for Waste Feed Evaporation Process (FEP)* (24590-PTF-3YD-FEP-00001). The FEP treats low-activity waste and process concentrates waste using a conventional forced-circulation, vacuum evaporation-crystallization system. System FEP employs one evaporator train in normal operation with a secondary train in standby. Two ejectors (per evaporator train) generate the vacuum requirements that enable boiling at approximately 122°F (50°C).

A block flow diagram of the FEP is provided in Figure 2.3.

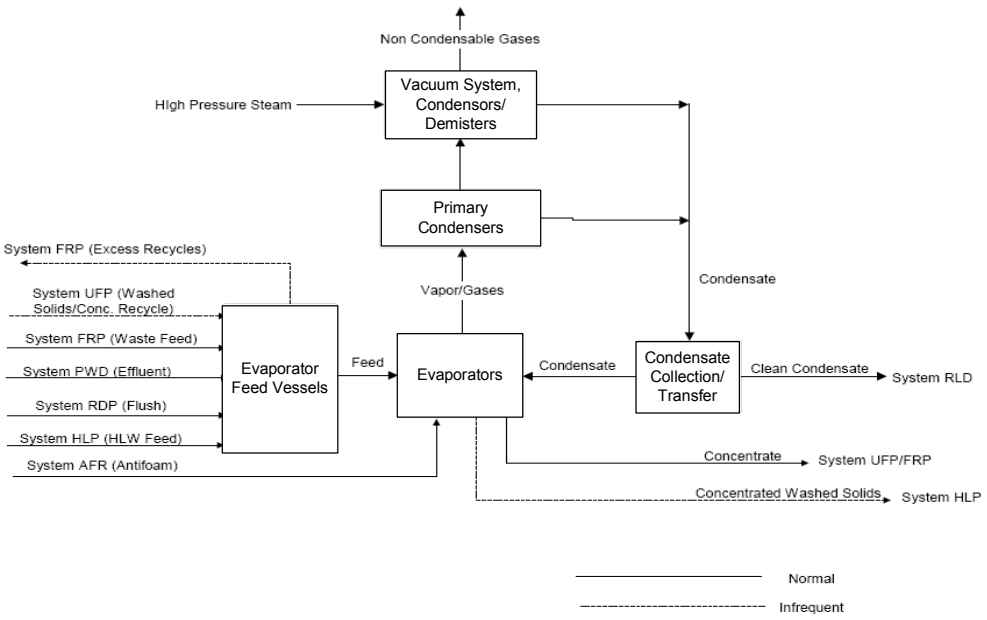

Figure 2.3. Block Flow Diagram for the Waste Feed Evaporation Process System

The FEP contains two waste feed evaporator feed vessels that receive waste feed and recycles. The evaporator feed vessels require continuous mixing with PJMs that turn off if the vessel level is below the PJM setpoint. Sampling ability in the feed vessels, although not required for production, is available to provide analytical information regarding evaporator feed properties. In the event the feed vessels require solids cleanout or decontamination (i.e., during decommissioning), the feed vessels will be washed down with vessel wash rings.

Evaporator feed is pumped from the feed vessels (FEP-VSL-00017 A/B) to the evaporator system. The evaporator system contains two evaporator trains of the same capacity (reboilers, separator vessels, and condensers). Although the evaporator trains can operate simultaneously (each contains independent control logic), a single evaporator train has sufficient capacity to support the maximum vitrification facility production requirements. The evaporators use conditioned steam (the steam system is operated under a vacuum to provide lower temperatures, which will prevent tube fouling) as a source of heat for the reboilers. The maximum boil-off rate per evaporator train is estimated to produce 30 gpm of condensate. Foaming tendencies in the separator vessel will be minimized by the addition of an anti-foam agent.

The vapors from each separator vessel are sent to a dedicated overhead system that is comprised of a primary condenser, vacuum ejectors, intercondenser, aftercondenser, and demisters. Water vapor generated by evaporation of waste is condensed in the primary condenser. The ejector uses steam to discharge the noncondensable gases to the aftercondenser, where the steam condenses. The vessel vent system draws noncondensable gases from the aftercondenser through the demister to remove any liquid entrained in the noncondensable gases. Liquids from each of these unit operations drain to the condensate vessel, where condensate vessel routing valves enable transfer to the RLD.

The condensate draining from the primary condenser is monitored for radioactivity by an area radiation monitor located close to the condenser. In the event the area radiation monitor detects high activity, the contaminated condensate is automatically redirected back to the separator vessel.

The evaporator bottoms are sent through the UFP process using the concentrate pumps. The concentrate pumps receive a permissive signal to run when density instrumentation indicates the evaporator bottoms have a liquid specific gravity of approximately 1.27 (1.27 is estimated to correlate with a Na concentration of 5 M).

Solids within the evaporator recirculation loop are maintained in a suspended state by the waste feed evaporator recirculation pump. If solids build up on the separator vessel wall above the liquid level, the walls will be washed with intermittent sprays. Purge air can be injected into the vapor space of the separator vessels to maintain the hydrogen concentration below the lower flammability limit.

Due to the dissolved salt content of the evaporator feed, there is the potential for solids deposition on vessel and reboiler tube surfaces; however, the potential for fouling has been minimized by employing a high vacuum design (to lower evaporation temperature), conditioned steam, and high recirculation rates. Crystallization is likely to occur at the liquid/vapor interface because of evaporation at the liquid surface. In order to remove solids deposits from the equipment, periodic washdowns will be carried out after transferring the entire separator vessel and recirculation loop contents to the UFP via the evaporator concentrate pumps. The vessel can then be filled with flush solution from the feed and concentrate flush lines, or dilute acid via the demister spray header. The flush solution would be used to dissolve crystallized salts and remove solids deposits. Following a routine vessel wash-down, the wash liquor will be boiled down. The resulting concentrate will be sent to the UFP for processing.

High-maintenance equipment exposed to highly contaminated fluids (reboilers, recirculation pumps, concentrate pumps, and feed pumps) are located in a hot cell, and the equipment must be remotely maintained. The waste feed evaporator feed vessels (FEP-VSL-00017 A/B) and the separator vessels (excluding de-entrainment section) (FEP-SEP-00001 A/B) are located in the black cell and will not be maintained over the life of the plant: The condensers, vacuum ejectors, and condensate collection vessel are contact maintained. The de-entrainment equipment can be accessed via shielding plug from 56-ft level for contact maintenance.

2.3.4.3 Relationship to Other Systems

Recycles are routed to the FEP feed vessels (FEP-VSL-00017 A/B) from the following systems:

- Effluents from the PWD vessel (PWD-VSL-00044) and acidic/alkaline effluent vessels (PWD-VSL-00015 and PWD-VSL-00016)
- Flush from the RDP vessels (RDP-VSL-00002 A/B/C)
- Recycle concentrate from the UFP (UFP-VSL-00001 A/B)
- Waste feed from the FRP (FRP-VSL-00002A/2B/2C/2B)
- HLW feed from the HLP (HLP-VSL-00022)
- Anti-foam from the Anti-Foam Regent System

In the event the ultrafiltration operation yields low solids concentrations (i.e., 10 wt % or less), the evaporator can provide a contingency operation to further increase the washed solids concentrations (up to 20 wt%).

2.3.4.4 Development History and Status

The FEP evaporator trains are similar to the Hanford 242-A Evaporator. Waste inventories that are dilute are concentrated in the Hanford 242-A Evaporator to a maximum specific gravity of approximately 1.44 (or 10 M Na). However, the 242-A Evaporator does not process waste solutions containing high solids content. The FEP evaporators are designed to produce a concentrate of 5 M Na, which is not intended to concentrate beyond the point of crystallization. The solids within the FEP evaporators primarily originate from suspended solids present in the feeds and recycles. It is anticipated that the suspended solids concentration in the evaporator product will not exceed 15 wt%. The system is not expected to perform beyond the demonstrated capability, but the evaporator includes more bubble trays than is typically used. The evaporator tower decontamination factor is not greater than what vendor data supports.

SRS personnel conducted modeling (SCT-M0SRLE60-00-154-05) of waste feed evaporator offgas and recommended more studies to address concerns over the partitioning of organics between the evaporator overhead and bottoms. The organic partitioning was significantly impacted by the amount of water being fed into the system from SBS recycle and ultrafiltration caustic wash. SRS personnel also identified the possibility of a hazardous mercury compound forming in the WTP evaporator overhead and service room (or other locations where sampling or maintenance is performed) (CCN:074276) after dimethyl mercury was found in the 3H evaporator process condensate and in the 3H evaporator overheads and service room (WSRC-TR-2003-00238).

The mechanical integrity of the demisting section due to erosion/corrosion effects over a 40-year operating life was identified as a primary concern (CCN:050417). WTP Plant Design personnel suggested that a single, large demister pad assembly could be first lifted up above 56-ft floor through the existing plug. The assembly could then be moved by crane north (for FEP demister pads) and positioned above a new plug leading into the hot cell. The assembly could then be lowered through the new opening on the 56-ft floor down to the hot cell floor for replacement and disposal of the old demister pads assembly once it is in the hot cell.

SRS personnel summarized testing for resolution of the project evaporation issues in the closure report (24590-PTF-RPT-RT-03-001) for the Research and Technology evaporator test program. Four issues were closed: (1) waste foams in the evaporator; (2) excessive aluminum silicate scale in the treated LAW evaporator; (3) LAW SBS condensate returns that produce uranium precipitates, and (4) dimethyl mercury in WTP evaporator overheads. These are discussed in more detail in Section 2.3.3.4. Foaming in the FEP was not considered significant and anti-foam agents were effective. Equipment will need to be periodically inspected for scale buildup during operations and cleaning performed as required. The criticality calculation showed that criticality issues for uranium precipitates were extremely unlikely. The formation of dimethyl mercury would not be expected at the mild operating temperature of the WTP evaporators. The effects of potential waste recycle streams from HLW, LAW, and the Analytical Laboratory on the evaporation process was not investigated.

During the bench-scale tests SRS conducted with non-radioactive simulants, it was discovered that additional solids precipitated during addition of the acid cleaning solution to the UFP recycle. The blended UFP recycle solution formed gels when the pH is reduced below 12 by the acid content of the cleaning solution. NaOH was therefore used to adjust the pH of the blended UFP recycle (WSRC-TR-2003-00238). The EFRT (CCN:132846) identified unresolved issues with chemical and physical plugging because some of the waste feeds have not been characterized. The Contractor's Mechanical Systems Process Technology and Engineering group is capturing approaches to reverse or mitigate line plugging in a design guide titled, *Avoiding Chemical Line Plugging - Plant Design Considerations* (24590-WTP-GPG-M-0059, Rev. 0 draft).

Other technology issues evaluated in the SIPP test are common to both the FEP and TLP. Results of this testing is described in Section 2.3.3.4.

2.3.4.5 Relevant Operational Environment

The operating environment for the FEP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001) and the FEP system description (24590-HLW-3YD-FEP-00001). The relevant environment for the FEP is the:

- The feed vessels (FEP-VSL-00017 A/B) shall operate by both filling and discharging at the same time or by alternating with one vessel filling and the other discharging.
- Operations shall vary cycle time according to equipment availability, operator preferences for recycle management, and throughput requirements.
- The vessel vent system shall maintain the hydrogen concentration to below the lower flammability limit.
- Black cell vessels shall retain their integrity under worst case service conditions (pressure, temperature, corrosion, erosion, mechanical loading, and seismic loading) for the lifetime of the PT Facility.

2.3.4.6 Comparison of the Relevant Environment and the Demonstrated Environment

The FEP was demonstrated in a relevant environment. It is projected that the FEP will achieve operational requirements in normal and challenge conditions because of the following design features that were added to the final WTP design to address identified issues.

Feed Vessels: Common to all operations is the principal requirement that if a feed vessel is receiving from a source vessel, no other source vessel outside of the FEP can discharge to that feed vessel.

Evaporators: Although the evaporator trains can operate simultaneously (each contains independent control logic), a single evaporator train has sufficient capacity to support the maximum production requirements (60 MT/day LAW glass and 6 MT/day HLW glass production).

2.3.4.7 Technology Readiness Level Determination

The FEP was determined to be TRL 4 because vessels in the FEP (FEP-VSL-00017A/18B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the FEP, is determined to be immature (e.g., TRL 4) until mixing issues on the PJMs are resolved.

The FEP evaporator design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site and is based on extensive lab-scale and pilot-scale prototypic testing that has been completed to demonstrate this technology. The FEP evaporator is a mature technology. Technology issues evaluated included: design scale-up, effect of organics and recycle streams on process chemistry, testing and identification of an anti-foaming agent, evaluation of the plate out of salts of aluminum and uranium salts on heat transfer surfaces, characterization of offgas effluents, and evaluation of the potential to form dimethyl mercury.

2.3.5 Ultrafiltration Process System (UFP)

2.3.5.1 Function of the UFP

The primary functions of the UFP are to: (1) receive waste feed and WTP recycles; filter and concentrate solids, wash solids, and leach solids; and (2) transfer permeate and solids for further treatment and immobilization. The UFP may also be used to carry out the precipitation process used to remove strontium (Sr) and transuranic (TRU) elements from complexed waste.

2.3.5.2 Description of the UFP Process

The UFP performs the initial process steps in the separation of Hanford tank waste into HLW and LAW fractions. The principal process steps include filtration that separates solids from liquids and washing/ leaching that dissolves non-radioactive species from the solids. The liquids and dissolved solids that pass through the ultrafilters (permeate) are sent to the CXP and the solids are sent to the HLW Vitrification Facility.

The UFP is presently undergoing redesign. The most recent version of the *System Description for Ultrafiltration Process System (UFP)* (24590-PTF-3YD-UFP-00001, Rev. 0) was issued September 11, 2002. Figure 2.4, taken from the system description, provides a basis for describing the UFP hardware and process flow. Modifications being considered during the current redesign efforts will be noted later in this section.

UFP Components: There are two parallel UFP processing trains: Two 48,000 gallon (batch volume) ultrafiltration feed preparation vessels, UFP-VSL-00001A and B, receive LAW feed from the FRP, high-level waste from the HLP, and/or evaporator concentrate from the FEP. They are also used for precipitation of Sr-90 and TRU from complexed wastes. PJMs are used to agitate vessel contents. The chemicals used for the precipitation of Sr-90 and TRU can be added to the top of UFP-VSL-00001A and B.

The 25,000 gallon (batch volume) ultrafiltration feed vessels, UFP-VSL-00002A and B, are used to perform solids washing and caustic and oxidative leaching on waste received from the UFP-VSL-00001A/1B vessels. The current design adds caustic, wash water and oxidative leaching reagents (sodium permanganate [$NaMnO_4$] and NaOH) to the top of vessels UFP-VSL -00002A/2B. PJMs and spargers are used to mix caustic with vessel contents. PJMs and pump recirculation are used to mix wash water and oxidative leaching chemicals. The Contractor is examining the possibility of using in-line mixing of chemicals in the recirculation line to shorten blend times. Mixing technology, including the PJMs, is evaluated separately in Section 2.3.6.

The ultrafilters receive waste from UFP-VSL-00002A/2B and separate the slurry into HLW solids and permeate liquid. The HLW solids are sent to HLP vessels (HLP-VSL-00027A/27B) and eventually to the HLW Vitrification Facility, and permeate liquids containing approximately 5 M Na are sent to two 22,000 gallon ultrafilter permeate collection vessels UFP-VSL-00062A and 62B and on to the CXP. Dilute wash/leachate permeate liquids are collected in UFP-VSL-00062C and sent to the PWD for eventual recycle to the waste feed evaporator for concentration. Each of the two cross-flow ultrafilter trains consists of three modules connected in series and laid out horizontally. Each module consists of a bundle of 241 porous stainless steel tubes. Each tube is 8 ft long, 1/2-inch inner diameter (ID) x 5/8-inch outer diameter (OD), and has a nominal filter pore rating of 0.1 micron.

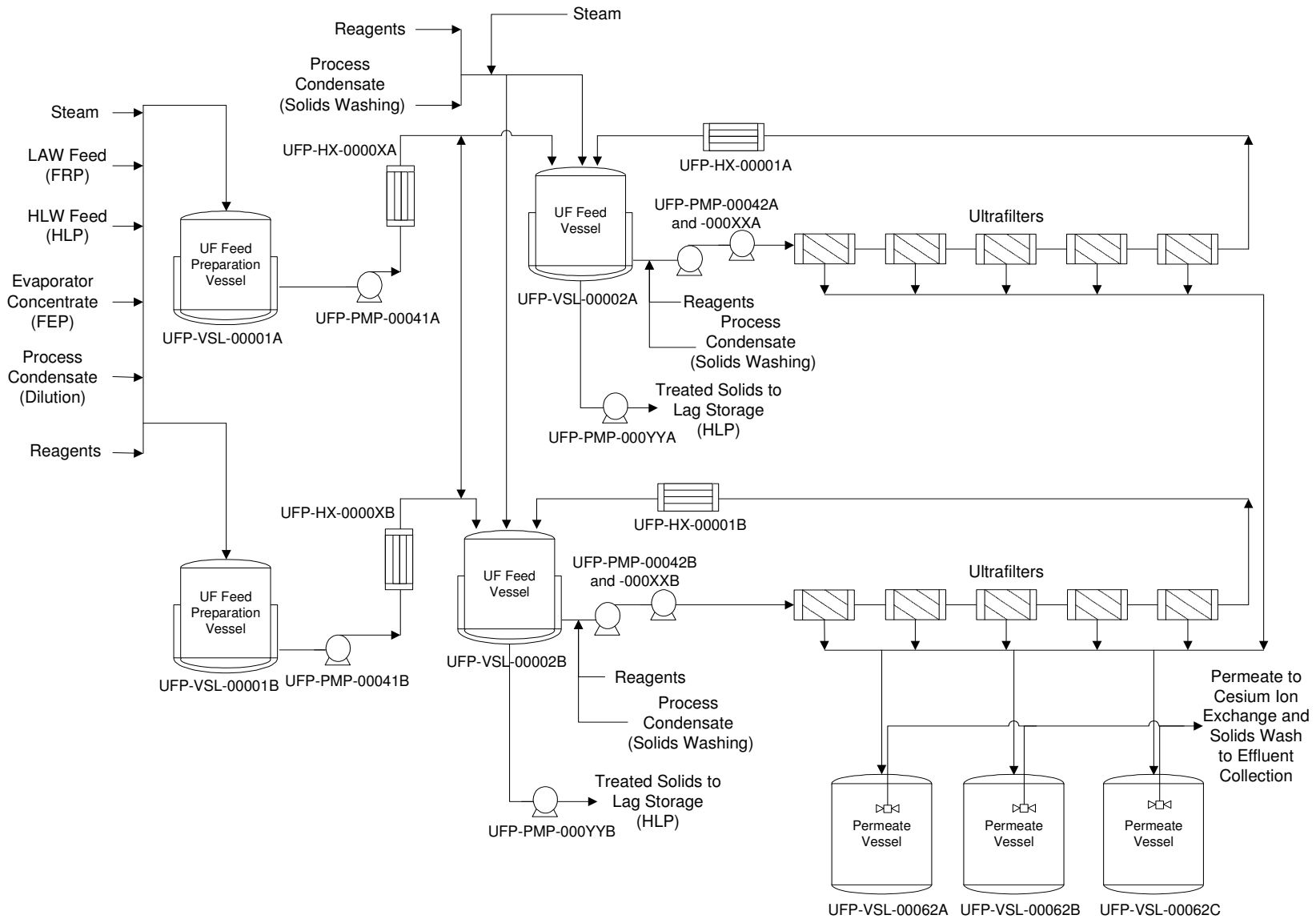

Figure 2.4. Ultrafiltration Process System Simplified Flow Diagram

The ultrafilters can be periodically backpulsed (a short pulse of permeate in the reverse direction) to flush solids from the filter surface. They can also be cleaned by soaking in process condensate, dilute nitric acid, or caustic. The goal of both backpulsing and cleaning is to restore filter flux levels.

The Contractor is examining a modification that would increase the number of modules in each ultrafilter train to five and lengthen the tubes in three of the modules to 10 ft. Filter units would be laid out horizontally. This modification would increase filter surface area by 92% to (from 602 ft^2 to 1,162 ft^2). This design change would also require placing a second pump in series with UFP-PMP-00042A and B in order to generate a required 70% increase in pump head.

UFP Process Description: The UFP is used for the following processes, each of which has its own process flow: concentration, washing, caustic leaching, oxidative leaching, and Sr/TRU precipitation. The two filter trains (A and B) operate independently. The following process flow descriptions are written for filter train A.

1. Solids Concentration (Filtration): Waste is received in vessel UFP-1A from HLP-VSL-00022, the FRP, and FEP. The volumes of the waste feed sources are adjusted to achieve a target concentration in vessel UFP-VSL-00001A of 4 wt% solids and 5 M Na. When vessel UFP-1A is full, and cooled if necessary, the waste is blended by PJMs, and transferred to vessel UFP-VSL-00002A using pump UFP-PMP-00041A. When vessel UFP-VSL-00002A is full, the waste is mixed using PJMs, the variable speed recirculation pump, UFP-PMP-00042A, is turned on and the waste slurry is pumped through the filters at the design velocity (12 to 15 ft/sec). Filter permeate is routed to permeate vessel UFP-VSL-00062A or B. The solids fraction is recirculated back to vessel UFP-VSL-00002A. Additional waste is continually transferred into UFP-VSL-0000A from UFP-VSL-0000A to make up for the loss of volume as permeate. Concentration of solids continues until the desired wt% solids are generated in vessel UFP-VSL-00002A. The present design target endpoint for solids concentration is 20%. Once concentrated, the waste will be washed with process condensate.

2. Caustic Leaching: Caustic leaching is only performed if warranted. If not warranted, then this step is skipped and the solids are washed. After solids concentration is complete, the recirculation pump, UFP-PMP-00042A, is turned off and enough 19 M NaOH added to make the liquid 3 M in hydroxide (OH). The resulting caustic solution in vessel UFP-VSL-00002A is then mixed, heated to 80° to 90°C, and digested until as much Al and other caustic soluble components as possible enter the liquid phase. The Contractor is investigating raising the leaching temperature to 100°C.

   After caustic leaching is complete (8 hours), the vessel contents are cooled to 25°C and the solids re-concentrated to approximately 20 wt%. The Contractor is investigating raising the filtration temperature to 45°C in order to improve flux rates limit the amount of NaOH that must be added and increase batch size. The caustic permeate is sent to vessel UFP-VSL-00062A/B/C and eventually on to the CXP.

   The Contractor is examining the possibility of carrying out caustic leaching in vessels UFP-VSL-00001A and 1B. This option would eliminate the time dedicated to leaching in vessels UFP-VSL-00002A and 2B.

3. Washing: The concentrated solids are washed with process concentrate to remove dissolved components such as Na and Al. The process concentrate is added while the concentrated waste is re-circulated through the ultrafilters. The wash permeate is routed to vessel UFP-VSL-00062A, B, or C (usually C) where it is collected and eventually sent on to the PWD for concentration by evaporation and eventual recycle to the waste feed. The washed solids may be sent directly to the HLW vitrification system (vessels HLP-VSL-00027A/B) or retained for oxidative leaching.

4. Oxidative Leaching: Some waste solids contain concentrations of chromium (Cr) that will severely limit HLW glass loading. Oxidative leaching studies are still in exploratory laboratory stages. However, present plans are to treat high Cr sludges with NaOH and $NaMnO_4$ in vessel UFP-VSL-00002A to remove as much Cr as possible. It is anticipated that the process will be carried out in UFP-VSL-00002A in recirculation mode. Process is performed at ambient temperatures (25°C) and the reaction time is nominally 6 hours. The leached solids will then be washed and concentrated. Leach and wash solutions will be sent to UFP-VSL-00062C and then to the PWD and processed in the FEP. Solids will be sent to the HLW Vitrification Facility.

5. Sr/TRU Precipitation and Removal: Some wastes contain complexants that keep HLW Sr-90 and TRU in the liquid phase. These wastes will be received from FEP at 6 M Na in vessel UFP-VSL-00001A, agitated, and heated to maintain the temperature at 50°C (normal operating temperature of FEP evaporator). NaOH, non-radioactive strontium nitrate ($Sr(NO_3)_2$), and $NaMnO_4$ will then be added and the vessel contents thoroughly mixed. After radioactive Sr-90 and TRU solids precipitate from solution (about a 4-hour reaction time), the vessel contents are cooled and transferred to vessel UFP-VSL-00002A where they are concentrated to approximately 15 wt% using the ultrafilters, washed with process condensate, and sent to the HLW Vitrification Facility. Ultrafilter permeate is sent to the PWD and processed in the FEP. The caustic and oxidative leaching steps are not performed on the Envelope C precipitate.

2.3.5.3 Relationship to Other Systems

UFP is the initial pretreatment system. It receives LAW feed from FRP, HLW feed from the HLP, and plant recycles and process condensate from the FEP. It also receives process chemicals from the Nitric Acid Reagent System, Sodium Hydroxide Reagent System, Sodium Permanganate Reagent System, and Strontium Nitrate Reagent System. It separates the soluble waste fraction from the solids fraction and sends the former to the CXP and the latter to the HLP. Wash liquids are sent to the PWD for eventual recycle.

2.3.5.4 Development History and Status

The development history and status of the UFP is best approached in terms of the physical system and the individual processes. This section will outline the development work that has been completed for the equipment and for each process.

The current baseline ultrafiltration design consists of two cross-flow ultrafilter trains each consisting of three filtration modules connected in series. Each module consists of a bundle of 241 porous stainless steel tubes. Each tube is 8 ft long, 1/2 inch ID x 5/8 inch OD and has a nominal filter cutoff of 0.1 micron. The trains are laid out horizontally. They are hard-piped so that the entire train must be lifted out and replaced as a unit.

The EFRT (CCN 132846) judged that the baseline filtration capacity was inadequate to allow for processing uncertainties and filter degradation over time and recommended that it be increased by a factor 2 to 3 to improve the margin and flexibility. The Contractor is examining a modification that would increase the number of modules in each train to five and lengthen the tubes in three of the modules to 10 ft, the two other filter modules would have 8 ft long filter tubes. Filter module units would still be laid out with a slight slope to horizontal. This proposed modification would increase filter surface area by 92%. It would also require placing a second pump in series with UFP-PMP-00042A and B in order to generate a required 70% increase in pump head.

The EFRT reviewed the proposed modification in January 2007 and issued two documents (*Review of Process Design Changes*, January 28, 2007, and *Review of Issue Closure Plans*, February 2, 2007) that expressed concerns about the drainage and flushing of the horizontal filter arrangement and the high pressure pumps. The latter review stated:

> "The proposed new arrangement for the ultrafilter with five modules connected in series may not provide sufficient drainage and may cause problems with residual slurry solids buildup in the lower tubes of each module.
>
> The need to remove and discard a complete five-module filter system because of a blockage or partial blockage, and its replacement with a new unit, may be both lengthy and costly.
>
> An alternate vertical arrangement of filter modules was strongly recommended by the reviewers. Such an arrangement would trap residual solids within the tubes themselves and have the potential to allow the removal of individual modules or tube bundles."

The Contractor enlisted Energy*Solutions* to develop a design concept for a vertical arrangement of filter modules. Preliminary Energy*Solutions* designs (ES-5501-G-0001) have incorporated the EFRT recommendations and increased filter surface area beyond that of the horizontal filter bundle arrangement. The vertical arrangement provides approximately 2.4 times the baseline filter area, and the horizontal filter arrangement as conceptualized by the Contractor provides about 1.9 times the surface area.

To fit more filter area in the confined hot cell space, the Energy*Solutions* concept eliminated one pulsepot, lowered the level of the pulsepots below the level of the filters, and eliminated the pressure transmitters between each filter bundle that allowed independent transmembrane pressure control on each bundle. These changes from the current design have not been thoroughly evaluated for impact on system operability. Impacts on hydrogen in piping and ancillary vessel requirements have also not been completed.

Hanford Site tank wastes are highly variable. They include liquids with small amounts (<1 wt%) of entrained solids and sludges from a variety of extraction and recovery processes. Confidence in the UFP and the associated processes will require substantial lab- and engineering-scale testing with real and simulated wastes.

Summary of Test Results

1. Concentration (Filtration): Ultrafiltration has been used in a variety of industries and the DOE. However, the EFRT (CCN:132846) concluded that "…the use of ultrafiltration in the WTP is a challenging application of this technology because of the high solids concentration target, which is beyond the typical application of this technology."

   Laboratory-scale filtration testing has been carried out on wastes from a limited number of tanks. The information gained from these tests has been used to estimate filter flux rates and their variation with filtration time and concentration and to develop simulants for laboratory- and engineering-scale testing.

   Table 2.3 summarizes the dimensions of the ultrafiltration test systems and the WTP baseline system and a proposed WTP modified system. Table 2.4 summarizes the ultrafiltration tests on Hanford Site wastes and simulants that have been carried out.

Table 2.3. Summary of Filtration Test Apparatus

	Lab-Scale	Bench-Scale (CUF)	Pilot-Scale (SIPP)	WTP Baseline	WTP Plant Modification
Material pore size	316 SS 0.1 and 0.5 micron	316 SS 0.1 micron	316 SS 0.1 micron	316 SS 0.1 micron	316 SS 0.1 micron
Tube Length	6 inch	24 inch	96 inch	96 inch	96 and 120 inch
Tube ID OD	0.5 inch 0.625 inch	0.375 inch 0.5 inch	0.5 inch 0.625 inch	0.5 inch 0.625 inch	0.5 inch 0.625 inch
Tube Arrangement	single tube	single tube	bundle of 7 tubes	3 bundles of 241 tubes in series	5 bundles of 241 tubes in series 1^{st}, 3^{rd}, 5^{th} bundles 120 inch long 2^{nd}, 4^{th} bundles 96 inch long
Tube Orientation	horizontal	horizontal	vertical	horizontal	horizontal
Pump	low shear	low shear	centrifugal	centrifugal	2 centrifugal in series

CUF - cells unit filter
SIPP - Semi-Integrated Pilot Plant
SS - stainless Steel

Table 2.4. Summary of Filtration Tests[1]

Tank	Type of Waste	Test Apparatus	Final Wt. % Solids	Notable Results	Ref
AN-102	entrained solids <0.1 wt%	cells unit filter (CUF)		filter fouled quickly	WTP-RPT-151
	precipitated strontium (Sr)/transuranic (TRU)		13.9		WSRC-TR-2003-00204 WSRC-MS-2005-00756
	simulant	Semi-Integrated Pilot Plant (SIPP)	25	pilot flux 10-87% below CUF PJM mixing during precipitation led to low flux	
AN-102/ C-104	precipitated Sr/TRU	CUF			WTP-RPT-151
AN-104	dissolved saltcake and entrained solids	CUF	1	filter could not be cleaned to original state	WSRC-TR-2003-00295
AN-105	simulant	bundle of 7 tubes, 40 inch long 0.375 ID x 0.5 OD, .1 micron	8		WSRC-MS-99-00467
AN-107	entrained solids <0.1 wt%	CUF		filter fouled quickly	WTP-RPT-151
	precipitated Sr/TRU		4		WTP-RPT-151
AW-101	entrained solids <0.1 wt%	CUF		filter fouled quickly	WTP-RPT-151
AY-102/ C-106	sludge	CUF	15	nitric acid (HNO_3) cleaning "ineffective"	WSRC-TR-2003-00240
	sludge simulant		16		
	sludge simulant	SIPP	24	SIPP flux 30-50% below CUF	WSRC-TR-2005-00105
AZ-101	neutralized current acid waste (NCAW) sludge	CUF	17.9	Test used 0.5 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151
	leached NCAW		22		
AZ-102	NCAW sludge	CUF	20	Test used 0.5 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151
	leached NCAW		20		
B-110	Bismuth phosphate ($BiPO_4$) sludge in dilute sodium hydroxide (NaOH)	lab-scale	8	Test used 0.1 micron pore size Graver filter. Graver filter is an anisotropic filter with a titanium oxide (TiO_2) coating on a 2 micron pore size sintered metal filter substrate	WTP-RPT-151
C-104	sludge, washed sludge, and leached sludge	CUF	20-23	Test used 0.1 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151

Table 2.4. Summary of Filtration Tests[1]

Tank	Type of Waste	Test Apparatus	Final Wt. % Solids	Notable Results	Ref
C-106	sludge in dilute NaOH	lab-scale	8	Test used 0.5 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151
C-107	sludge in dilute NaOH	lab-scale	8	One test used 0.1 micron pore size Graver filter. Second test used 0.5 micron pore size Mott isotropic, sintered metal filter.	WTP-RPT-151
	combination of supernatant and leach and wash solutions			no solids visible in feed no solids on filter	
S-107	sludge in dilute NaOH	lab-scale	8	Test used 0.5 micron pore size Mott isotropic, sintered metal filter	WTP-RPT-151
U-110	sludge in dilute NaOH	lab-scale	7.5	Test used 0.1 micron pore size Graver filter.	WTP-RPT-151

[1] Except as noted, 0.1μm Mott filter used for all tests.

Examination of existing technology testing data contained in the references of Table 2.4 leads to the following conclusions:

- There is cells unit filter (CUF)-scale and lab-scale filtration data for 15 of 177 tanks.
- Waste from only four tanks has been concentrated to > 15%.
- Whole, major groups of tank waste compositions have not been tested at any scale.
- Large-scale (SIPP) tests have been conducted on only two simulants, which is only approximately 5% of the total volume of tank waste planned for processing.
- SIPP tests on simulants yield fluxes substantially below CUF results for the same simulants.
- CUF tests on entrained solids in four tanks show rapid dropoff in filter flux as the solids concentrate. Dilute wastes seem to be more difficult to filter. This suggests that low solids LAW should not be processed by itself and the Sr/TRU constituents in Envelope C tanks should be precipitated prior to filtration. [*Note: The WTP does not plan to process the dilute waste from tanks AN-104, AN-105, and AW-101 in the UFP. These wastes will be mixed with HLW feeds and processed in the UFP.*]
- Backpulsing tests were generally inconclusive with regard to restoring filter flux. The SIPP backpulsing (not entirely prototypic) showed some improvement in flux but it was not sustained. Backpulsing may be more useful in off-normal conditions such as restoring a fouled filter. Nitric acid cleaning is often ineffective and generally unable to return filters to original state.
- There is almost no filtration data on caustic and oxidatively leached waste.

WTP-RPT-151, *Review of Caustic Leaching Testing With Hanford Tank Waste Sludges*, draws the following additional conclusions for the filtration data it examined:

- Solids are recycled much more in CUF tests than is prototypical. [It appears that this plus the CUF pump alters the particle size.]

- Some of the simulants tested have not mimicked the waste chemistry and physics.
- Waste chemistry can change significantly with blending of waste types, resulting in precipitation of new and different solids that can have a major, catastrophic impact on filter behavior.
- Waste concentration by evaporation can form new solids that are more difficult to filter. Specifically, calcium carbonate ($CaCO_3$) and sodium oxalate solids may form, which are more difficult to filter.
- A used filter, cleaned with a clean 1 M HNO_3, exhibits a water flux of approximately half a new filter.
- Nitric acid alone is not always effective in cleaning a filter: oxalic and nitric/oxalic acid mixes [and NaOH] have been used in some cases.
- Envelope C [complexed] waste could not be filtered without first treating it with strontium carbonate ($SrCO_3$) and $NaMnO_4$ [to precipitate Sr/TRU]. The waste appears to contain polymer-colloidal solids that blind the filter.

2. Washing and Caustic Leaching: WTP-RPT-151 has summarized washing and caustic leaching data. Table 2.5 lists the wastes that have been tested and gives removal efficiencies for phosphorus (P), Al, and Cr. Tests have been carried out on a laboratory-scale with small quantities (<100 grams) of waste, under a variety of leaching and washing conditions. Most of the wastes have been washed and leached at several temperatures and NaOH concentrations, with 95° to 100°C and approximately 3 M NaOH, respectively, being the most common. Wash solutions, leachate, and washed/leached solids were analyzed for a variety of elements to determine removal of non-radioactive and radioactive species from the solid phase. Rheology and crystalline phases were also analyzed for most samples. Parametric studies were carried out on a number of wastes to determine the effect of time on leaching efficiency.

   As Table 2.5 illustrates, caustic leaching on a laboratory-scale has been carried out on waste from a relatively large number of tanks. The results for Al and P removal are variable but generally >50 to 90%. Cr removal is very variable. Caustic leaching, by itself, is unlikely to be adequate to remove Cr to acceptable levels. However, it is also clear that there is limited information for several waste classifications. Recent work (WTP-RPT-137, *Oxidative Alkaline Leaching of SX-101 and SY-102 and Its Impact on Immobilized High-Level Waste*) concludes that caustic leaching will probably remove 70 to 80% of sulfate from tank solids; however, WTP-RPT-137 also recommends this value should be verified by caustic leach testing on selected high-sulfate sludges.

   Extensive work has been done on characterizing the physical and chemical properties of the leached sludges including their morphology and rheology (WTP-RPT-151). However, there is very little information on the filterability of the leached sludges.

Table 2.5. Summary of Washing and Caustic Leaching Information from WTP-RPT-151

Group ID	Major Waste Type	Tanks Tested	Results Removal Efficiency
1	Bismuth phosphate ($BiPO_4$) sludge	B-104[1], -107[1], -110, -111 BX-107, -112 T-104, -107, -110, -111 B-201, B-202	P generally >90% Al generally <70% Cr generally <70%
2	saltcake (BY, T)	BX-110[2] BY-104, -108, -110	P variable 22 to 90% Al generally >90% Cr generally <50%
3	PUREX cladding sludge	BX-103,-105[3] C-102, -103[4], -104, -105	P minor element Al generally >90% except C-103 (52%), C-107 (22%) Cr variable
4	Reduction oxidation (S Plant) (REDOX) cladding sludge	U-108, -109	P not reported Al 54-81% Cr 5-13%
5	REDOX sludge	S-101, -104, -107[5], 110, -111 SX-108	P generally 65-99% Al variable 30-90% Cr generally >80%
6	S-saltcake (S) most tanks have low amounts of entrained solids	SY-103	P 98% Al 90% Cr 10%
7	tri-butyl phosphate (TBP) sludge	B-106 BX-109	P >90% Al >80% Cr 60-80%
8	FeCN sludge	TY-104	P 98% Al 63% Cr 86%
9	neutralized current acid waste (NCAW) sludge	AZ-101, -102	P 60% Al 80% Cr 60%
10	tanks containing a mixture of wastes	B-101 C-106, -107 -108, -109, -112 SX-113 SY-102 U-110	highly variable
11	a saltcake	AN-104	

[1] Tank also contains BY saltcake waste
[2] Tank also contains $BiPO_4$ sludge
[3] Tank also contains TBP and PUREX cladding sludges
[4] Tank contents transferred to a double-shell tank
[5] Tank also contains REDOX cladding sludge

A recent report (WTP-RPT-137, pg. 5.2) has concluded that "it would difficult to produce Hanford tank sludge simulants that would accurately mimic the partitioning behavior of the actual waste sludge solids in the caustic leaching and washing process." If this is correct, engineering-scale testing of caustic leaching and filterability of the resulting product using simulants would not be useful.

Given the limited amounts of waste sludges that can be handled due to the radioactivity levels and the difficulty of obtaining samples, it is unlikely that engineering-scale testing using actual waste will be possible.

It is clear that the variable nature of the sludges will require that each batch of sludge sent to the WTP be tested in the lab before optimal plant conditions can be specified.

3. Oxidative Leaching: Early work at Pacific Northwest National Laboratory investigated the efficacy of various oxidants, caustic concentrations, temperature, and leaching times. Exploratory laboratory tests were carried out on wastes from eight tanks. Oxidants investigated included $NaMnO_4$, oxide (O_3), air, and sodium ferrite (Na_2FeO_4). MnO_4^- was determined to be effective and compatible with WTP processing. The leach conditions tested were not chosen to represent potential WTP processes. WTP-RPT-117, *Oxidative Alkaline Leaching of Washed 241-SY-102 and 241-SX-101 Tank Sludges*, contains a review of the work done to date, and WTP-RPT-117 and WTP-RPT-137 contain the latest detailed investigations of the oxidative leaching of tanks SX-101 and SY-102 and its effects on glass loading. These later investigations used test procedures that more closely resemble potential WTP processes. Potential reagents were evaluated by the Contractor, and a recommendation was made to use $NaMnO_4$ (24590-PTF-ES-PR-05-001; 24590-WTP-RPT-ENG-05-006).

   The oxidative leaching process is in the early laboratory stage of development. The combination of caustic leaching and MnO_4^- has been determined to be an effective means to solubilize Cr. The small-scale laboratory tests on tanks SX-101 and SY-102 sludges have shown that it is possible to remove >95% of the Cr, more than enough to eliminate Cr as the limiting factor on HLW glass loading. The earlier work seems to indicate that leaching effectiveness may be substantially less than 90% for some sludges. However, the earlier work did not optimize reaction conditions. Additional work is needed to optimize the concentrations of NaOH and MnO_4^-, the sequence of chemical addition, and the time and temperature of operation. No work has been done on the filterability of oxidatively leached sludges.

   Besides optimizing the conditions for Cr removal, attention will have to be given to the possibility of solubilizing plutonium (Pu) during the process. Solubilized Pu will pass through the ultrafilters and enter the LAW stream where it would be a concern if it concentrates during subsequent processing (e.g., on the ion exchanger), reaches levels in the LAW glass that would cause the glass to be classified as TRU, or affects the performance assessment for the LAW burial site. The work contained in WTP-RPT-117 and WTP-RPT-137 indicates that it is possible to adjust the oxidative leach process to limit Pu solubility to levels considerably below those that would cause LAW glass to become TRU waste or, if necessary, to precipitate and remove soluble Pu in a subsequent processing step. However, more laboratory work is needed

4. Sr/TRU Precipitation and Removal: This process will be required for two waste tanks. Tests of the process have been carried out on tank AN-102, a mixture of AN-102/C-104 sludge leachate, and AN-107 wastes (WTP-RPT-151). The process appears to be effective, and the resulting solids have been shown to be filterable (WTP-RPT-151; WSRC-TR-2003-00204; WSRC-MS-2005-00756). The untreated waste rapidly clogs ultrafilters, and the process seems to require efficient mixing of reagents and sludge to produce filterable products (WSRC-TR-2003-00204).

2.3.5.5 Relevant Environment

The UFP will be required to process waste from a majority of Hanford's 177 underground storage tanks. The waste is chemically and physically variable, and limited physical and chemical characterization data is currently available. Although most tanks have been sampled, available waste samples are limited in

size (a few liters at most) and number. Solid waste samples may not be representative of the tank contents or of the waste as it will be fed to UFP for the following reasons:

- Waste solids in any given tank may vary horizontally and vertically. Different wastes were often deposited during multiple transfers and most likely did not settle in uniform layers. Vertical core samples of tank solids taken from different locations in the tank often bear little resemblance to each other.
- Core samples may not be representative. Most tanks are 75 ft in diameter. Core samples are 1 inch in diameter. Few tanks have had more than two core samples taken.
- Waste from a number of tanks will most likely be blended intentionally or inadvertently as it is staged for delivery to the WTP.

Consequently, the UFP will process a wide variety of wastes; the precise processing behavior of which will not be determined prior to staging for the WTP. Efficient processing of the waste will depend on having robust processing capability that has been determined by as comprehensive a set of waste and simulant testing as possible. Each batch of waste will have to be tested as it is staged in the tank farms and received at the WTP in order to determine efficient operating parameters.

2.3.5.6 Comparison of the Relevant Environment and the Demonstrated Environment

1. Ultrafiltration: Laboratory-scale filtration testing has been carried out on wastes from fewer than one tenth of the Hanford Site tanks. Waste from only four tanks has been concentrated to more than 15% due to limitation on sample volume. Pilot-scale testing is limited to simulants derived from two tanks; it is not known if the wastes tested are bounding. Major groups of wastes have not been tested.

   There is almost no ultrafiltration data on sludge that has been caustic leached. There is no ultrafiltration data on sludge that has been oxidatively leached. Laboratory-scale filtration data exists for Sr/TRU precipitated from both of the tanks containing wastes identified as requiring this processing step and engineering-scale data from simulant based on one tank.

2. Washing and Caustic Leaching: Washing and caustic leaching has been carried out at laboratory-scale on wastes from approximately one third of the tanks; however, the waste types in these tanks represent approximately 80% by volume of the sludge in the single-shell tanks and approximately 60% by volume of the sludge in double-shell tanks.

3. Oxidative Leaching: The final oxidative leaching process has not been experimentally determined. Exploratory laboratory-scale testing, not representative of anticipated WTP processes, has been carried out on wastes from eight tanks. Laboratory-scale testing that is more representational of possible WTP processes has been carried out on waste from two tanks.

4. Sr/TRU Precipitation and Removal: There are two tanks that contain complexed waste, AN-102 and AN-107. Laboratory-scale Sr/TRU precipitation and removal testing has been carried out on waste from both tanks and a simulant based on the wastes from AN-102.

The following provides a summary of commercial usage of ultrafiltration technology relevant to the design of the UFP:

Filters:

- Nuclear waste treatment – The Enhanced Actinide Removal Plant (EARP) (Sellafield) uses three filters in series for primary dewatering of ferric-based sludge (conc to 1-1.5 wt%), single filter for secondary dewatering to 10 wt% (consistency of toothpaste). This plant started hot operations in

1993 and has run continuously without any major problems. Reliability data from EARP between 1995 and 1999 shows a failure rate on the 13 filters of 0.08/year. This was based on the original CARBOSEP® and Ceraver ceramic filters, which relied on an elastomeric gasket to seal the tubes at the tubesheets. All failures were attributable to organic attach of this material causing it to soften and flow. Since 1999, the filters in EARP have been changed out for an all-welded, all-stainless steel design, and although reliability data is not available, it is likely to be significantly less than for the ceramic units. Since commencement of operations, there have been no problems or failure of the harness seal between the cartridge plug and the housing. The WTP design is all-welded construction and there are no seals subject to failure.

- Nuclear waste treatment – Oak Ridge National Laboratory Melton Valley, two in series for waste sludge, concentrated to 15 wt%. No performance details are available for this operation.
- Nuclear power stations – Four projects in wastewater treatment, 4 to 6 filters in series, 20 to 40 gpm permeate, low solids endpoint.
- Non-nuclear – Series filters are commonly applied in ultrafiltration and reverse osmosis.

Pumps:

- Weir Slurry identifies – Approximately 60 projects, mostly in the mining industry, with up to 8 pumps in series for slurry pipelines up to 35,000 gpm and very high heads with slurry particles up to 900 microns average size.
- Nuclear waste processing – No specific examples identified.

Pulsepots:

- Independent ultrafilter expert (Dr. Klaus Julkowski) suggested the UFP could be designed with a single pulsepot supporting three filters (CCN:032059) for space considerations and wall penetrations. This configuration has been utilized in full-scale operations (no references available). The WTP Project elected to use three instead of one to reduce backpulse line length. Current studies by Energy*Solutions* in the vertical filter study are revisiting the backpulse concepts for optimization of space considerations.

Ancillary Components:

- Spiral heat exchangers used for slurry service industrially. No known applications to nuclear waste processing.
- Filter cleaning strategies are consistent with industry practice. Avoiding overconcentration is the first line of defense. Flexibility is provided in the WTP design for alternate cleaning methods. Testing is planned to evaluate filter draining.

2.3.5.7 Technology Readiness Level Determination

The WTP ultrafiltration technology design is supported by a history of successful design and operation of relevant systems in both radioactive and non-radioactive service. However, specific pilot testing in a prototypical configuration on relevant waste simulants has not yet been performed to confirm efficiency of the UFP system for meeting throughput requirements.

The UFP was determined to be a TRL 3 because:

- The WTP ultrafiltration technology design has only been conceptualized on paper. There is no representative testing platform available for technology evaluation. However, the WTP Contractor is completing the design of an engineering-scale testing system for testing and evaluation.

- The oxidative leaching process is limited to proof of principle tests, and the final process has not been determined. Additional work is required to optimize the concentrations of NaOH and MnO_4^-, the sequence of chemical addition, and the time and temperature of operation.
- There is very little data on the filtration of caustic leached waste and no filtration data on oxidatively leached waste.
- Hot bench-scale testing will be used to evaluate the effectiveness of the UFP components; optimize NaOH and $NaMnO_4$ concentrations, sequencing, and timing; and demonstrate filtration of treated sludge wastes.
- Pilot-scale testing using simulants to demonstrate efficacy of flowsheet design concepts.
- Demonstration of integrated system will be performed at engineering-scale. Larger scale testing may be required pending evaluation of the results generated in the engineering-scale tests (24590-PTF-TSP-RT-07-001, Rev. A).

Based upon the low technology maturity of the UFP, it is recommended that:

Recommendation 5

Development and testing at a laboratory-scale with actual wastes, and at an engineering-scale with simulants, should be completed in prototypical process and equipment testing systems to demonstrate all detailed flowsheets for the UFP prior to final design. The testing should validate the scaling methodology for mixing, chemical reactions, and filter surface area sizing; determination of process limits; and recovery from off-normal operating events.

Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-12, "Undemonstrated Leaching Process," and WTP Baseline testing of the Oxidative Leaching Process.

Recommendation 6

Evaluation of a vertical modular equipment arrangement for the UFP filter elements for increasing the filter surface area should be continued. The design configuration (currently proposed horizontal or vertical orientation of the filters) that has the highest probability of successfully achieving performance requirements should be thoroughly tested in high fidelity, prototypical engineering-scale tests using simulants that represent a range of tank waste compositions. Testing scope should include all filtration system operations, process flowsheets (caustic and oxidative leaching and strontium/transuranic precipitation), high-temperature filtration, and filter back pulsing, cleaning, draining, and replacement. Based on the results of this testing, a design concept (either the horizontal arrangement proposed by the Contractor or the vertical arrangement conceptualized by Energy*Solutions*) should be selected for final design.

Supporting Recommendations

- The strategy and method to scale the ultrafiltration processes (mixing, chemical reaction and filter surface area) to predict performance of the ultrafiltration system should be established to ensure a high-fidelity UFP engineering-scale test platform and support useful interpretation of the testing results.

2.3.6 Pulse Jet Mixer (PJM) System

2.3.6.1 Function of the PJM System, Pulse Jet Ventilation System, and Pretreatment Vessel Vent Process System

The function of the PJM system is to mix waste streams comprised of liquid and solids in specially designed vessels to dissipate gases, blend liquids and solids, and suspend solids for sampling and transport.

2.3.6.2 Description of the PJM System

The PJM and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003).

PJM devices are long cylindrical vessels that draw in fluid by a vacuum and then pressurize to partially eject the fluid to cause mixing; much like a syringe draws in and expels fluid. These devices have been shown to be reliable and have no moving parts that require maintenance. Thus, the PJM was selected to be used in vessel systems that were designed to have no maintenance over the 40-year operational design life of the WTP.

The PJMs can be operated either in a continuous pulsing mode, or turned off for a time and restarted in the pulsing mode, depending on process requirements. In vessels that contain particulates, the solids will settle to the bottom between mixing periods. When the PJMs restart, settled solids must be re-suspended.

A PJM system consists of the following components:

- Valves
- Fluidic controller assembly
- Jet pump pair
- Piping
- PJM vessels fitted with nozzles, located in the process vessel

The operating concept for the PJMs is presented in Figure 2.5.

A jet pump is used to pull a vacuum on the PJM and draw process fluids into the PJM vessel from the process vessel. This is the suction phase of the PJM cycle. When the PJM vessel is full, the jet pump is switched from vacuum to pressure mode. This is called the drive phase. Air pressure applied to the PJM vessel is used to force fluid back out of the PJM vessel and into the process vessel, thereby mixing the process vessel contents. The application of pressure is halted prior to the complete discharge of fluids from the PJM such that no air is discharged into the process vessel (a condition called overblow). The PJM is then vented to depressurize the PJM. This is the vent phase of the cycle.

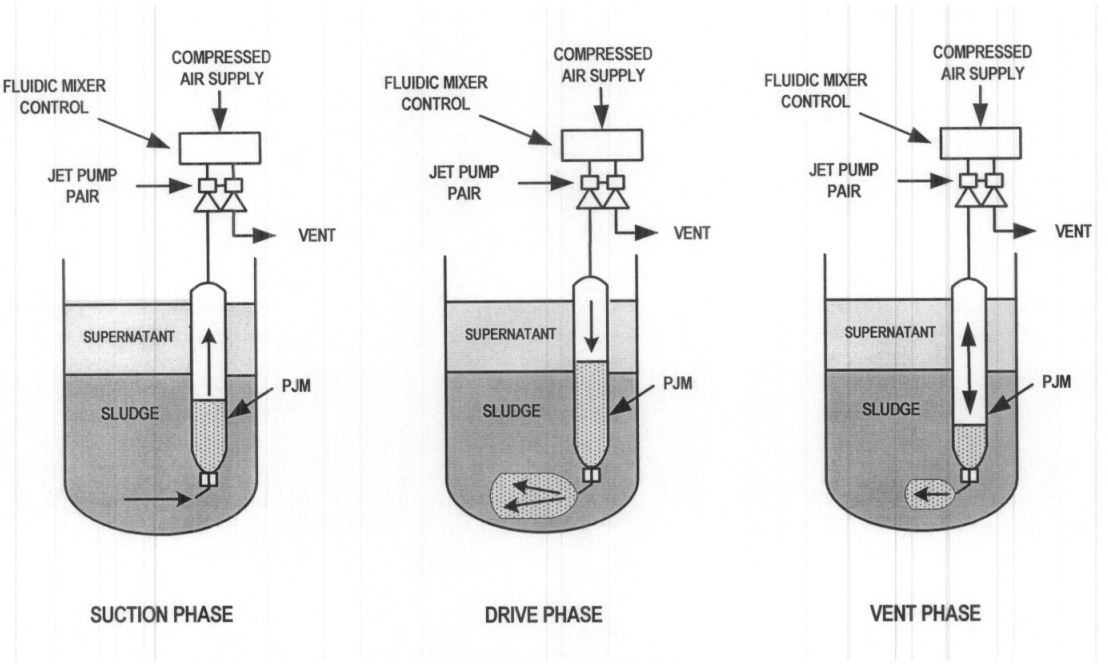

Figure 2.5. Operating Principles of a Pulse Jet Mixer

2.3.6.3 Relationship to Other Systems

The WTP vessels that contain PJMs are summarized in Table 2.6. This table presents the vessel number, common name, material of construction, number of PJMs in each vessel and vessel capacity. The primary interfaces with the PJM system are the vessels; the air supply to the PJMs is provided by the Plant Service Air System. The offgas treatment for the PJM is the *Pulse Jet Ventilation System* (24590-PTF-3YD-PJV-00001).

Table 2.6. Summary of PJMs in WTP Pretreatment and HLW Vitrification Facilities

Vessel Number	Common Name	Vessel Material of Construction	Number of PJMs	Nominal Vessel Capacity, kgal
CNP-VSL-00004	Cesium Nitric Acid Recovery Vessel	304L	4	6
CXP-VSL-00004	Cesium IX Caustic Rinse Collection Vessel	304L	1	6
CXP-VSL-00026A/26B/26C	Cesium Ion Exchange Vessels (3)	316L	6	26
FEP-VSL-00017A/17B	Waste Feed Evaporator Feed Vessels (2)	316L	8	50
FRP-VSL-00002A/2B/2C/2B	Waste Feed Receipt Vessels (4)	316L	12	375
PWD-VSL-00015	Acidic/Alkaline Effluent Vessels	316L	8	80
PWD-VSL-00016	Acidic/Alkaline Effluent Vessels	316L	8	80
PWD-VSL-00033	Ultimate Plant Overflow Vessels	316L	8	15
PWD-VSL-00043	Ultimate Plant Overflow Vessels	316L	8	15
PWD-VSL-00044	Plant Wash and Disposal Vessel	316L	8	60
RDP-VSL-00002A/2B/2C	Ion Exchange Spent Resin Collection and Dewatering Vessels (3)	316L	4	8
RLD-VSL-00007	HLW Radioactive Liquid Waste Disposal Vessels (2)	316L	4	9

Table 2.6. Summary of PJMs in WTP Pretreatment and HLW Vitrification Facilities

Vessel Number	Common Name	Vessel Material of Construction	Number of PJMs	Nominal Vessel Capacity, kgal
RLD-VSL-00008	HLW Radioactive Liquid Waste Disposal Vessels (2)	316L	4	6
TCP-VSL-00001	LAW Concentrate Storage Vessel	316L	8	93
TLP-VSL-00009A/9B	LAW SBS Condensate Receipt Vessels (2)	316L	8	80
UFP-VSL-00062A/62B/62C	Ultrafiltration Permeate Vessels (2)	316L	6	22
CNP-VSL-00003	Eluate Contingency Storage Vessel (1)	316L	4	12
HLP-VSL-00022	HLW Blend Storage Vessel	316L	12	160
HLP-VSL-00027A/27B	HLW Lag Storage Vessels (2)	316L	8	86
HLP-VSL-00028	HLW Feed Receipt Vessel	316L	8	81
HOP-VSL-00903/904	SBS Condensate Receiver Vessels (2)	C-22	4	6
UFP-VSL-00001A/1B	Ultrafiltration Feed Preparation Vessels (2)	316L	8	48
UFP-VSL-00002A/2B	Ultrafiltration Feed Vessels (2)	304L	6	25

2.3.6.4 Development History and Status

PJM Design Concept Development

The PJM design concept was based on technology developed jointly by United Kingdom Atomic Energy Agency (UKAEA) and British Nuclear Fuels Limited, Inc. (BNFL). The PJM technology is used in some nuclear facilities in the United Kingdom. The PJM design concept for mixing of fluids was used in the initial WTP design completed by BNFL and BNI. A description document (24590-CM-TSA-HXYG.0008) was prepared by BNFL in 2001 to provide the technical basis for the use of the PJMs in the initial WTP conceptual design phase (September 1996 to May 2000). During the conceptual design phase, vessels with PJMs were identified along with the following: vessel capacity and dimensions, number of PJMs, and fluid properties (i.e., temperature, specific gravity, viscosity, and solids content). The basis for the specifications was not provided to DOE.

Following WTP contract award to BNI in December 2000, the design development for the PJMs (and fluidic devices) mixing technology was discontinued until September 2002 when AEA Technology Inc. was subcontracted by BNI to provide the PJM and fluidics systems designs. In December 2002, AEA Technology issued *Fluidics Design and Methodology Report; Pulse Jet Mixing Systems* (24590-QL-POA-MPEQ-00002-04-03; ESI Document No. 2141-04-116). This design methodology report outlined the approach to complete the design of the PJMs and identified the relative roles of AEA Technology and BNI (buyer) in this design process. Major observations and steps in the design methodology included:

- The buyer is to provide the vessel dimensions (diameter, height, liquid operating levels), liquid properties (density, viscosity, temperature, vapor pressure), solids properties (density, particle sizes, concentration), mixing duty requirements, and length of air piping to jet pump pair.
- AEA Technology will complete a preliminary design of the PJMs based on information provided by the buyer and the following major assumptions:
  - The PJMs have a maximum area of influence of 17 m^2 based on vessel plan area.

- The volume of the pulse tubes assumes 5% of the maximum liquid volume if the solids are less than 5 wt%, and the volume of the pulse tubes is 10% of the maximum liquid volume if the solids are greater than 5 wt%.
- The height of the pulse tube is below the maximum liquid level. From this information, the diameter of the pulse tube is determined.
- The pulse tube nozzle diameter is 0.1 m (4 inch).
- The target drive velocity is 8 m/sec.

The preliminary design did not take into account the liquid and solid physical properties.

- The buyer will conduct Computational Fluid Dynamic (CFD) modeling to verify the adequacy of the PJM design. AEA Technology will review the CFD analyses.
- AEA Technology recommended that "arduous mixing duties are subjected to physical testing, by construction of a suitable testing facility and operation of a prototype PJM system using simulants." The criteria for decision on whether or not testing is required will include (but are not limited to):

  "The level of confidence in the results of the CFD analysis.

  The extent to which difficult to predict chemical reactions may occur within a vessel, which may affect fluid properties.

  The Quality Assurance and Quality Control requirements related to the mixing system (e.g., sampling accuracy, homogeneity levels etc.)

  The extent to which the mixing duty falls outside previous experience."

In 2003, BNI was unable to achieve acceptable confirmation between their CFD analysis and the proposed AEA Technology PJM designs for the high solids containing vessels (UFP-VSL-00002A/2B, HLP-VSL-00027A/27B, HLP-VSL-00028, and the HLW concentrate receipt vessels (CRV), which have been subsequently removed from the WTP flowsheet). The CFD analysis determined that the CFD model was not capable of simulating the complex non-Newtonian flow relationships and it was decided at that point to launch a test program to evaluate the design. The non-Newtonian fluids in the case of the WTP vessels was bounded by laboratory test data as having a Bingham plastic yield stress of 30 Pa and a consistency viscosity of 30 cP. Non-Newtonian fluids can have high viscosities (>100 Pa) if they are not periodically sheared by mixing systems. This fluid property potentially allows the accumulation of quantities of hydrogen in excess of the lower flammability limit for hydrogen (4%). Based on this analysis, BNI initiated an extensive testing program to develop and validate the designs for these high-solids containing vessels. The testing process led to subsequent phases of research and design development, testing, and ultimately implementation of a significantly different PJM configuration (using a PJM cluster) compared to the WTP conceptual design. This test program determined that PJMs in combination with spargers could successfully mix non-Newtonian fluids to release hydrogen gas.

The potential for excessive hydrodynamic loads from PJM overblows (large surge of air rather than slurry released from the pulse jet nozzle) that could result in a potential accident condition was identified in April 2004. Since the development of a mixing system for the high-solids containing vessels, the program has focused on the development of an integrated control system to assure avoidance of PJM overblows. The control system is currently undergoing testing.

The project timeline for the development of the PJM fluid mixing technology is presented in Table 2.7.

Table 2.7. Timeline of PJM Analysis and Development for the WTP

Date	Event/Activity
June 2000	BNFL completes conceptual design of PJM and fluidics mixing systems for WTP.
August-December 2000	AEA Technology continues fluidics design for WTP. The AEA Technology mixing criteria was simple: Vessels that contain no solids required a pulse volume of 5% of the vessel volume and those with high solids required a pulse volume of 10% of the vessel volume.
January-September 2001	AEA Technology continues to advance WTP conceptual design under CH2M HILL Hanford Group, Inc. Transition Contract (WTP project activities transitioned to BNI in April 2001).
August 2001	BNFL issues *Technical Basis for River Protection Project Waste Treatment Plant (RPP-WTP)-Power Fluidics System Design* (24590-CM-TSA-HXYG.0008). The document indicated adequacy of the PJM concept for WTP application. The report concluded that testing was required to develop and optimize the "suck and drive" type PJMs in high-solids bearing liquors and high-viscosity floc liquors.
October 2001 to September 2002	Extended period of negotiations between BNI, and AEA Technology and BNFL on intellectual property rights on fluidics technology and contracting.
March 2002	Overall plan for Computational Fluid Dynamics (CFD) analysis developed to support vessel delivery schedule. Newtonian vessels are planned for fabrication significantly in advance of non-Newtonian vessels.
April 2003	WTP determines CFD modeling will not accurately reflect actual fluid behavior of non-Newtonian fluids contained in seven WTP facility vessels.
June 2003	BNI's Pulse Jet Mixer Task Team develops an integrated strategy for scaled testing to validate PJM mixing in WTP vessels containing non-Newtonian fluids. In addition, WTP Project funded work to determine WTP-specific hydrogen generation rate source terms and gas transport characteristics in representative scaled prototypic mixing configurations during PJM operation.
June 17, 2003	WTP Pulsed Jet Mixing and Hydrogen Release for Process Vessels Containing Non-Newtonian Slurries Action Plan approved. Trend 852 - Non-Newtonian Fluid PJM Mixing Tests approved by WTP. Trend 867 - Hydrogen Testing approved by WTP.
August 1, 2003	WTP awards PJM testing scope to Battelle (Pacific Northwest National Laboratory) and Savannah River Technology Center.
August – November 2003	BNI CFD analysis determines that vessels FRP-VSL-00002A/2B/2C/2D and HLP-VSL-00022 may not meet off-bottom suspension criteria.
September 15, 2003	BNI Pulse Jet Mixer Task Team initiates scaled platform testing of pulse jet mixing baseline design.
October 10, 2003	Initial (physical) scaled testing confirmed that the baseline pulse jet designs in the seven vessels containing non-Newtonian fluids did not mix slurries to the extent necessary to meet WTP design requirements. BNI Pulse Jet Mixer Task Team initiates Phase I of PJM testing to determine alternate design.
December 15, 2003	BNI's Pulse Jet Mixer Task Team presents Phase I "PJM-only" design configurations to Engineering, PT Facility, and HLW Vitrification Facility personnel.

Table 2.7. Timeline of PJM Analysis and Development for the WTP

Date	Event/Activity
January 5, 2004	WTP determines implementation of the PJM-only mixing systems severely impact the WTP facility designs due to increased numbers of PJMs, additional piping, and the significantly larger air consumption necessary to operate the systems. To minimize overall project cost and schedule impact, the BNI Pulse Jet Mixer Task Team initiates Phase II of PJM testing which investigates further alternative designs to assess the effects of slurry rheology changes, reduced tank volume, PJM jet velocity and nozzle size, sparging, and recirculation pump operation.
March 2, 2004	BNI Pulse Jet Mixer Task Team recommends Phase II PJM hybrid mixing systems configurations for UFP and large-scale (LS) to Engineering, Pretreatment, and HLW Vitrification Facility personnel. PT Engineering chooses PJM hybrid mixing systems design configurations.
April 2, 2004	HLW Engineering chooses PJM hybrid mixing systems design configuration for HLW Facility concentrate receipt vessel (CRV).
April 2, 2004	BNI Pulse Jet Mixer Task Team issues document supporting testing basis for the selected UFP-VSL-00002A/B, HLP-VSL-00027A/B, and HLP-VSL-00028 PJM and sparger configurations to Engineering for review.
April 2, 2004	BNI Pulse Jet Mixer Task Team issues document supporting testing basis for the selected UFP-VSL-00002A/B, HLP-VSL-00027A/B, and HLP-VSL-00028 PJM and sparger configurations to Engineering for review.
January 10, 2006	Corrective action on overblow loads issued that required additional testing (24590-WTP-MVE-50-00006).
March 2006	EFRT identifies mixing issues with the PJMs including long mixing times in high-solids vessels and ability of the PJMs to suspend large particles (CCN:132846).
January 11, 2007	Summary Report: *Hydrodynamic Loads for PJM Multiple Over blow Condition* (24590-WTP-RPT-M-06-003).
March 2007	WTP Project analysis (24590-WTP-RPT-PR-07-002) using BHR Group jet correlation indicates that FRP-VSL-00002A/2B/2C/2D, HLP-VSL-00022 and PWD-VSL-00044 will not meet off-bottom suspension criteria and FEP-VSL-00017A/17B, PWD-VSL-00033, PWD-VSL-00043 will not meet off-bottom suspension criteria with 50% of the PJMs operated at a time (50/50 criteria) mixing.
April 2007	Draft test plan to evaluate PJMs for mixing of low solids containing process streams prepared.
April 2007	Testing of ICN control of PJM overblows.

Summary of Testing to Support Low-Solids Containing Fluids: The WTP Contractor has not developed any representative testing data in prototypic PJM mixing test systems to demonstrate the mixing of prototypic low-solids containing (Newtonian) slurries. Some testing was completed by BNFL (the WTP Contractor prior to BNI) on Newtonian slurries. This testing (BNFL-RPT-048) evaluated the mixing performance of PJMs using a Newtonian simulant at solids concentrations of 17 wt%, 28 wt%, and 38 wt%. The Newtonian simulant was based on the properties of tank AZ-101/AZ-102 at a pH of 12. The PJM test configuration was described as having used much higher power per volume of fluid compared to the WTP design. However, the testing documentation does not provide sufficient detail to determine the power level. Despite this, the study concluded:

- The PJM system in the test system, operating at a maximum frequency was able to mix the 28 wt% and 38 wt% fluids.
- With the faster settling slurries (e.g., the 17 wt%), the results indicated stratification in the test vessel occurred at maximum PJM operating frequency.
- BNFL had also summarized the historical use of the PJMs at the Sellafield site (24590-CM-TSA-HXYG.0008). This data shows that the BNFL development program evaluated a number of simple simulants, formed with water and fine silica, potassium carbonate, and magnesium hydroxide at concentrations that varied between 2 and 48 wt%. The vessels used in the Sellafield facilities had volumes that ranged from 133 gallons to 50,000 gallons, which in general are much smaller than the WTP vessels. No mixing performance data other than the data presented in BNFL-RPT-048 was provided in the document.

A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:

- The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling, and paid less attention to Newtonian slurries with low solids concentrations that settle rapidly.
- Large dense particles may be more difficult to suspend than those used in the current design, and may be difficult to re-suspend.
- The zone of influence (ZOI) for the PJMs in Newtonian vessels may be over estimated for large dense, rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is indeterminate.
- The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems and may not be sufficiently validated for the dynamics of PJM operation and should be matched to relevant experimental results.

In response to these issues, the WTP Contractor has prepared an IRP for EFRT issue M-3, “Inadequate Mixing System Design” (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries.

Summary of Testing to Support High-Solids Containing Fluids: Extensive non-radioactive simulant testing has been conducted by the WTP Contractor to test the PJM and vessel design concepts for mixing, off-bottom suspension, solids uniformity, gas retention, and release in wastes containing high-solid concentrations. These studies were focused on establishing the minimum design and operational requirements based on the testing scope for the vessels that are nominally referred to as containing non-Newtonian wastes. These vessels are UFP-VSL-00002A/00002B, HLP-VSL-00027A/00027B, and HLP-VSL-00028.

Nine different test stands were constructed for the phases of the scaled testing. These test stands are identified in Table 2.8. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, ZOI, aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests.

Table 2.8. Summary of PJM Test Vessels and Applications

Vessel	Internals	Description	Scale	Volume, gal	Purpose
Applied Process Engineering Laboratory (APEL) Single PJM	1 PJM	Single pulse tube in clear acrylic vessel	NA	250	Select and develop simulant; demonstrate PJM cavern formation.
4 PJM Scaled Vessels					
336 Supernatant Tank (SNT)	4 PJM	4 pulse tubes in stainless steel vessel	1	10,000	Demonstrate scaling approach for PJM mixing and GR&R in WTP vessels containing non-Newtonian slurries. Also, overblow tests in 336 SNT.
APEL 4 PJM	4 PJM	4 pulse tubes in clear acrylic vessel	1/4 scale of 336 4 PJM SNT	250	
Savannah River National Laboratory (SRNL) 4 PJM	4 PJM	4 pulse tubes in clear acrylic vessel	1/9 scale of 336 4 PJM SNT	30	
Scaled prototypes					
UFP Scaled Prototype	Variable PJMs, spargers, recirculation pump	Scaled prototype representing UFP vessel	1/4.94 scale of full-scale UFP vessel	350	Assess performance of a variety of vessel internal configurations, including the number of PJMs, size and angle of PJM nozzles, drive velocity, sparging and recirculation pumps.
Large-scale (LS) Scaled Prototype	Variable PJMs, spargers, recirculation pump	Scaled prototype representing LS and blend vessels	1/4.29 scale of full-scale LS vessel	1,000	
CRV Scaled Prototype	Variable PJMs, spargers, recirculation pump	Scaled prototype representing CRV vessel	1/4 scale of CRV	230	

Table 2.8. Summary of PJM Test Vessels and Applications

Vessel	Internals	Description	Scale	Volume, gal	Purpose
Half-scale LS vessel and cone-bottom tank (CBT)					
HSLS Vessel	8 PJM Cluster (7 around 1), 7 spargers	Half-scale LS vessel	1/2 of full-scale LS vessel	10,000	Assess GR&R and mixing in the LS vessel with WTP operational cycles.
Cone Bottom Tank	Spargers	9 spargers in tank with cone shaped bottom	Similar to 336 SNT	10,000	Develop sparger design guidelines for mixing; provide data on gas release and aerosol entrainment.

Key testing reports and results are summarized below:

- *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is the summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels. This report summarizes the results of technology testing, which includes:
  - Simulant Development: A transparent simulant based on Laponite (a synthetic layered silicate material) was developed and used in the early phases of testing. Laponite properties were varied by changing the concentration. Shear strengths ranged from 30 to 120 Pa and consistency from 10 to 20 cP. An existing kaolin-bentonite clay simulant was tailored for the PJM program by varying the concentration of the clay components in the 20 to 30 wt% range. Most of the testing was conducted near the upper-bound rheological properties of 30 Pa for yield stress and 30 cP for consistency. Over the course of all testing, yield stress varied from about 5 to 47 Pa and consistency from about 14 to 41 cP. Simulant development efforts are summarized in WTP-RPT-111, *Non-Newtonian Slurry Simulant Development and Selection for Pulsed Jet Mixer Testing*. Simulants representing chemical, rheological, and physical properties of pretreated waste samples from Hanford Site tanks AZ-101 and AZ-102 were also used.
  - PJM Scaling Relationship Development: Tests were conducted in three, scaled PJM test stands each containing four PJMs, using Laponite and kaolin-bentonite simulants at large 1/4- and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113, *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries*, and WSRC-TR-2004-00430, *One-Eighth-Scale Pulse Jet Mixer (PJM) - Design Parameters Scale Law Testing*.
  - Large-Scale (LS) PJM Testing: Tests were conducted in the large-scale cone-bottom tank (CBT) using a kaolin-bentonite clay simulant. Test results are reported in WTP-RPT-129, *Technical Basis for Scaling of Air Sparging Systems for Mixing in Non-Newtonian Slurries*, and include the following information:
    1. ZOI and region of bubbles dimensions were determined for air flow rates from 5 to 40 acfm. Measurement methods included ultrasonic velocity probes, a laser reference system coupled with video analysis, and passive integrated transponder tags.
    2. ZOI circulation time was established with dye and tracer tests.
    3. The time to establish steady-state flow profiles was determined with velocity probes.

4. Aerosol measurements were obtained using impaction plates to collect samples.
5. GR&R characteristics were determined by generating oxygen in situ by hydrogen peroxide decomposition followed by sparging.

- Gas Holdup Studies: Several gas holdup (representing hydrogen) and release tests were conducted in the scaled prototypes of the HLW lag storage vessel, ultrafiltration, and concentrate receipt vessels. Various combinations of PJMs, spargers, and recirculation pumps were tested using a kaolin-bentonite clay simulant. Retained oxygen gas was generated in situ by decomposition of hydrogen peroxide. The technical basis is reported in WTP-RPT-114, *Final Report: Gas Retention and Release in Hybrid Pulse Jet-Mixed Tanks Containing non-Newtonian Waste Simulants*, and WSRC-TR-2004-00399, *Final Report – Gas Retention and Release Tests Supporting the Concentrate Receipt Vessel (CRV-VSL-00002A/2B) Configuration*.
- Demonstrate PJM/hybrid mixing Configurations: Several hundred tests were conducted in scaled prototype vessels representing the LS/blend and UFP vessels and HLW CRV. Tests conducted included mixing, off-bottom suspension, solids uniformity, GR&R, and velocity mapping. Results of the scaled prototype PJM only tests (Phase I) are reported in WTP-RPT-110, *Test Results for Pulse Jet Mixers in Prototypic Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, and WSRC-TR-2004-00398, *Final Report – Hybrid-Mixing Tests Supporting the Concentrate Receipt Vessel (CRV-VSL-00002A/2B) Configuration*. Results of scaled prototype PJM/hybrid tests (Phase II) are summarized in WTP-RPT-128, *Hybrid Mixing System Test Results for Prototype Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels*, and WSRC-TR-2004-00399.
- Demonstrate mixing and gas retention and release characteristics: A series of tests was conducted in a half-scale replica of the lag storage vessel. These tests were conducted using the kaolin-bentonite clay simulant. Retained oxygen gas was generated in situ by the decomposition of hydrogen peroxide. These tests demonstrated: (1) a normal operating mode consisting of continuous PJM mixing and intermittent sparging; (2) post-design basis event (DBE) operations consisting of intermittent PJM and sparger mixing; and (3) near-term accident response operations consisting of intermittent sparging (no PJMs). The time to achieve 95% homogeneity was also determined using the chloride tracer method. The results of the half-scale LS demonstration reported in WTP-RPT-114.

- *Demonstration of Ability to Mix in a Small-Scale Pulsed-Jet Mixer Test Facility* (24590-101-TSA-W000-0004-124-03): This report documents the results of small-scale-pulsed jet mixer (SS-PJM) testing focused on addressing several issues associated with the effectiveness of the PJMs in the baseline design of Sr/TRU precipitation and sludge-washing processes. The SS-PJM facility description is not provided in Table 2.8. The objectives of the tests were to determine the following:
  - Influence of a density gradient on the mixer performance.
  - Mixing time of liquids of dissimilar densities.
  - Optimum mode of addition of reactants.
  - Cycle frequency to achieve best mixing performance.
  - Operating volume, pressure and vacuum optimum range to minimize air entrainment.
  - Validation of the TEMPEST CFD model of the PJMs using the data generated in the small tank.

  A mixing time criterion of one hour or less (at SS-PJM scale) was derived from pilot-scale experiments at the SRS. Experiments in the SS-PJM that were performed at the plant design-target specific energy did not produce acceptable mixing even within 90 minutes. (At small scale, all reagents were added in a static layer prior to test commencement to preclude scaling issues related to reagent addition unduly influencing test outcomes). Mixing time was reduced to 40 minutes at

3 times the design-target specific energy; experiments at 5 and 14 times the design-target specific energy produced mixing times of 33 minutes and 15 minutes, respectively. *Although the small tank experiments indicated acceptable to good mixing at three times or higher multiples of the design energy/volume conditions, extreme caution was recommended in using this data to predict full-scale performance due to complexities associated with scaling pulsed jet mixers.*

Objective 2 above was fully achieved, and Objectives 1 and 4 were partially achieved. Objective 3 was addressed insofar as the static bulk addition was a conservative condition for the top-addition (reagent) configuration. No parametric study was performed of air entrainment (Objective 5) because during the review of the test plan this objective was considered out-of-scope for the SS-PJM test series. Validation of the TEMPEST CFD model (Objective 6) was attempted, but results were inconclusive. Significant modifications to the code would be necessary to produce satisfactory results. Because the SS-PJM is not geometrically and kinematically similar to the prototype PJM, it was concluded that the level of effort required to modify the code was not justified.

- *Results of Small-Scale Particle Cloud Tests and Non-Newtonian Fluid Cavern Tests* (24590-101-TSA-W000-0004-72-08): The objective of the cloud height tests was to obtain experimental measurements of the effective mixing heights for BNI to use in benchmarking the FLUENT computer code. The cloud height measurements were obtained for a single steady-state jet directed downward in an elliptical bottom tank. The cloud tests used glass beads in water to evaluate the height of the suspended slurry as a function of jet velocity. The objective of the cavern tests was to obtain experimental data to validate the non-Newtonian fluid modeling capabilities of the computer code for fluid properties similar to those of certain tank wastes. A transparent material that exhibited a yield stress and shear thinning behavior was used to obtain measurements of steady-state cavern heights as a function of jet velocity. The simulant also exhibited time-dependent behavior. To evaluate the influence of the time dependent behavior, constant shear rate tests were carried out. The measured shear stresses dropped continually for the first 20 minutes. After approximately 20 minutes, the change in shear stress was less than 1%. The magnitude of the change in rheological properties at steady-state conditions over the time steady-state measurements were made was negligible. This document summarizes the tests and presents the experimental results produced at the SS-PJM test setup in the Applied Process Engineering Laboratory (APEL).

- *Large Tank Experimental Data for Validation for the FLUENT CFD Model of Pulsed Jet Mixers* (24590-101-TSA-W000-0004-118-02): The objectives of the work were to develop and experimentally validate the TEMPEST CFD model of the PJM system using: (1) small-tank hydrodynamic (water) data; (2) large-tank hydrodynamic (water) data; (3) column simulant settling data; and (4) large-tank simulant data. All of the objectives, except Objective 4, were met. The inability to validate the model using the large-tank simulant data was primarily due to the asymmetries of the flow fields in the tank, which made the data insufficient to complete the validation of code.

  The settling sub-model validation results indicated that the model predictions matched the experimental density profiles in the settling column for the first few hours of the test, after which discrepancies on the order of 15% were observed. The errors are primarily due to the difficulties in precise estimation of the unhindered settling velocities of the particles in the slurry tested since these particles exhibit a broad range of particle size distribution. Earlier work with settling of actual Hanford Site waste shows that these models can replicate the settling behavior of complex wastes provided a reasonable estimation of the unhindered settling velocities is available. The small-tank hydrodynamic validation results indicated an excellent match between the model predictions and the experimentally measured velocity profiles near the tank-floor and the tank-wall regions. These results suggest that the TEMPEST PJM model captures the hydrodynamic flow behavior in previously untested flow regimes. The large-tank hydrodynamic validation results indicated that the

match between the experimental velocity data and the model predictions is acceptable given the asymmetries in the flow behavior and the uncertainties in the velocity and liquid level change measurements (used to determine the drive function). In the case of the large-tank simulant validation, the asymmetries of the flow fields in the tank, made the data insufficient to complete the validation of code. However, none of the results invalidated the code. It was not possible to repeat the large-tank simulant tests due to budgetary and schedule constraints.

- *Technical Basis for Testing Scaled Pulse Jet Mixing Systems for Non-Newtonian Slurries* (24590-101-TSA-W000-0004-114-00016): The purpose of this work was to establish the technical basis for performing scaled testing of PJM systems. This scaling approach was required to design, conduct, and apply results of tests in reduced-scale prototypic Hanford WTP PJM mixing systems. The scaling approach consisted of two key components, theoretical analysis and experimental confirmation.

  Theoretical analysis included developing a physical model for the cavern position resulting from a single, downward-oriented, steady jet operating in a non-Newtonian slurry. This model used heuristic arguments involving elemental turbulent Newtonian jet theory coupled with a static force balance between the impinging jet and slurry cavern boundary. The model was extended to accommodate non-physical model; the dependence of cavern position on various physical parameters was evident. Normalized cavern height (cavern height divided by vessel diameter) was found to depend on the yield, Reynolds number, the jet Reynolds number, the ratio of PJM nozzle diameter to vessel diameter, and the non-dimensional pulse time (ratio of PJM volume to nozzle diameter cubed). Cavern heights predicted by the single PJM model were found to be in good agreement with measured cavern heights in Laponite and clay simulant. The physical model also demonstrates the relative importance of various parameters affecting cavern height and provides insight into the optimal operation of PJMs. In addition to the development of the physical model, dimensional analysis and physical insight were used to identify the important non-dimensional parameters affecting the performance of PJM mixing systems. The relative importance of the various parameters was analyzed, and those considered dominant were identified. Evaluating how these non-dimensional parameters changed with physical test scale led to the scaled testing approach.

  The scaling laws and the non-dimensional parameters determined to be most important to the non-Newtonian mixing problem required experimental validation. Therefore, an experimental test strategy was developed that involved performing mixing tests using 4PJM arrays at three different scales, including a large-scale vessel in the 336 Building at Pacific Northwest Division (PNWD) that had a capacity of about 12,000 gallons, PJM diameter of 24 inches, and PJM nozzle diameter of 4 inches; a 1/4.5-scale version of the 4PJM vessel in the APEL building at PNWD with a capacity of about 250 gallons, PJM diameter of 5.3 inches, and PJM nozzle diameter of 0.9 inches; and a 1/8.9-scale vessel at Savannah River National Laboratory (SRNL) with a capacity of about 18 gallons, PJM diameter of 2.63 inches, and PJM nozzle diameter of 0.45 inches. The tests used two non-Newtonian simulants, a kaolin-bentonite clay mixture, and Laponite. Experimental data collected from the geometrically scaled test stands were compared at similar conditions to confirm and demonstrate the methodology for predicting large-scale behavior from the small-scale test results.

- *Final Report: Gas Retention and Release in Hybrid Pulse Jet Mixed Tanks Containing Non-Newtonian Waste Simulants* (24590-101-TSA-W000-0004-153-00002):

  – Measure and report gas holdup volumes in simulants during steady-state PJM operation: Gas-holdup volumes were measured at several gas-generation rates and with various combinations of mixing methods (spargers, recirculation, and PJMs) in the LS and UFP prototypes using configurations and operating conditions determined in previous mixing studies to have acceptable performance. Gas-holdup tests were also successfully completed in a generic

configuration of four PJMs in three test stands (336 Building 4PJM and APEL 4PJM at Battelle—PNWD and SRNL 4PJM) representing different sizes (scaled) of the system. Holdup varied from less than 1 to over 3 vol%, generally correlating with gas-generation rate, simulant depth and rheology, and PJM drive-cycle parameters.

- Experimentally measure and report gas-release characteristics (i.e., rates and volumes) in a loss-of-power scenario: The transient decrease in gas-volume fraction was measured for restarting mixing systems after a period of gas accumulation in the LS and UFP prototypes with configurations similar to those used in the gas-holdup tests. Additional gas-release tests were completed in the 336 4PJM system, the APEL 4PJM system, and a small-scale 4PJM system at SRNL. Sparging-only gas-release characteristics were investigated separately in the 336 cone-bottom tank. The gas release data show that gas-release behavior is influenced by simulant rheology, gas bubble size as deduced from the more rapid gas releases in tests that accumulated gas overnight, and somewhat by initial gas fraction. Full-coverage sparging was shown to be very effective at releasing retained gas.

- Measure and report consistency of gas-release rates and volumes for a series of intermittent mixing cycles: A series of three repeated gas-release tests was completed in the APEL 4PJM system on consecutive days using the same approximately 100 gallons (~380 L) batch of kaolin-bentonite clay and approximately the same initial gas fraction (3.7 to 4.3 vol%). Rates and volumes are reported. Results indicate release behavior is nominally repeatable.

- Determine mass-transfer coefficients and gas holdup in kaolin-bentonite clay and pretreated tank AZ-101 slurry simulants in bench-scale apparatus: Bench-scale bubble-column devices were used to measure gas holdup and mass-transfer coefficients in two kaolin-bentonite clay dilutions and a pretreated tank AZ-101 slurry simulant. The gas holdup was a significant function of gas superficial velocity, slurry consistency, and the concentrations of $NaNO_3$ and anti-foaming agent. The scaled oxygen mass-transfer coefficients were in good agreement for the three simulants tested at the bench-scale. A similar proof-of-concept gas-stripping test was conducted in the APEL UFP prototype vessel containing an initially oxygen saturated kaolin-bentonite clay simulant. The mass transfer coefficient determined in the UFP test was approximately half that estimated from the correlation established in the bench-scale studies (1.27/hour).

Additional testing has been completed or is underway to evaluate overblow of PJMs using the Building 336 testing system and evaluating the impact of anti-foam on gas release.

The Contractor is relying on CFD analysis, as compared to testing, to validate the performance of the PJM technology for vessels that are mixed with PJMs only. The CFD model has been validated using experimental data from small-scale particle cloud tests (24590-101-TSA-W000-0004-72-08) and the large-scale tank (24590-101-TSA-W000-0004-118-02). The validation of the CFD model is described in 24590-PTF-RPT-PR-06-002, *Benchmarking of Computational Fluid Dynamic Simulation of Pulse Jet Mixers Using Experimental Data*. This assessment demonstrates close agreement between the CFD results and the experimental results in predicting mixing performance, and provides confidence that can be used to judge whether a mixing vessel will pass or fail specified mixing criteria. This assessment however is limited to the range of conditions evaluated.

Materials of construction for the PT Facility vessels have been established through a corrosion evaluation assessment (24590-WTP-GPG-M-047). Corrosion evaluations are based upon a detailed design guide used by the WTP Contractor that considers process chemistry, mechanisms for corrosion, and erosion. These have been previously reviews and evaluated by DOE and have been determined to be acceptable based on current operating conditions (05-WED-019).

2.3.6.5 Relevant Environment

Overall requirements for the PJMs are briefly described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). The relevant operational environment for the PJM system is:

- Support a 40-year operational design life.
- Suspend and mix solids with the bulk fluid to ensure the release of hydrogen.
- Blend solid and liquids to support a determination the received waste is acceptable with the safety and environmental permitting authorization basis.
- Blend solid and liquids to support all process operating requirements including ensuring efficiently of chemical reactions, ensuring uniform process stream transfers and control of the pretreatment and HLW vitrification processes.

2.3.6.6 Comparison of the Relevant Environment and the Demonstrated Environment

The discussion on the comparison of the relevant environment and demonstrated environment is divided into: (1) fluids that contain low-solids content in which the solids rapidly settle (referred to nominally as Newtonian fluids); (2) high-solids content, shear thinning fluids (referred to nominally as non-Newtonian fluids); and (3) adequacy of the definition of technology requirements that are derived from design requirements.

There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed (BNFL-RPT-048) do not sufficiently describe the test conditions that allow a comparison between the test conditions and the current design.

Benchmarking of the CFD simulation using experimental data (24590-PTF-RPT-PR-06-002) indicates that the CFD simulations predict more uniformity than indicated by experiment, and do not provide conservative and bounding estimated of mixing behavior. However, the relatively close agreement between the experimental data and the CFD simulation indicated that the CFD analysis would be useful to rate the adequacy of the PJM design solution.

The testing of high-solids containing slurries has been exhaustive and is described in detail above. However, this testing has been focused on off-bottom suspension, solids uniformity, GR&R in wastes containing high-solid concentrations hydrogen release, and not on meeting other important requirements of the vessel designs. This testing is incomplete based on a review and evaluation of the requirements identified in several project documents described below.

Work associated with the EFRT IRP M3 relating to “Inadequate Mixing System Design” will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

<u>PJM Design Requirements</u>

The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:

- Re-suspend settled solids and maintain suspension of solids within vessels.
- Provide blending of cold chemicals with active process liquids.
- Sufficiently mix the contents of the vessels for sampling.

Specifically, the flow velocities of the PJMs must be great enough to mix the vessel contents sufficiently to meet WTP operational constraints, and to enable disengagement of hydrogen bubbles to mitigate flammability safety concerns.

The *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003) repeated these general mixing requirements for PJMs and provided general requirements for different vessel groups. In some cases, these requirements were quite specific; for example:

- For CNP-VSL-00003/4 (Cs nitric acid recovery and concentrated Cs eluate vessels), the vessel must mix in preparation for sampling. Provide for the blending of 2,400 gallons of 0.25 M NaOH with 3,600 gallons of water within one hour.

In other cases, the mixing requirements have been generalized; for example:

- For HLW-VSL-00022 (HLW feed receipt vessel), the mixing must prevent solids accumulation, facilitate hydrogen evolution, and provide a representative sample to support waste acceptance criteria for feed to the WTP.

24590-PTF-M0D-M40T-00002, *Process Data Sheet: Fluidics*, which is used as an input to PJM design by AEA Technology provides further requirements for mixing. For example, the following requirements (summarized in Table 2.9) are provided for the HLP-VSL-00022:

- Prevent solids accumulation and facilitate hydrogen evolution.
- Provide representative sample to support waste acceptance criteria (95% confidence level).

A recent document defining *Pulse Jet Mixer Mixing Test Performance Criteria* (24590-WTP-RPT-PR-07-003) provides additional requirements to support testing as part of the IRP for EFRT issue M-3 (24590-WTP-PL-ENG-06-013). General requirements included for HLP-VSL-00022:

> "Suspend up to 200 g/l solids for sampling and transfer. Suspend solids in normal operations for hydrogen release. Mobilize solids sufficiently to release hydrogen post-DBE."

The definitions for maintaining solids suspended from 24590-WTP-RPT-PR-07-003 are briefly summarized below:

> "…the mixing must be sufficient to maintain the solids in suspension so that they do not accumulate on the bottom and so they can be transferred out with the fluid, through the pump suction line." [pg. 2]
>
> Sampling to support criticality evaluation is specified in the WTP Criticality Safety Evaluation Report. The criticality evaluation requires a sample of the solid fraction, so the distribution of specific types of particles is important. However, it is expected that the elements of interest to criticality will be in the heavier particles, so the sample taken near the bottom of the vessel will be bounding. Therefore, the just suspended or off-bottom condition is adequate to meet this requirement.

> Additional mixing requirements are defined in the *Integrated Sampling and Analysis Requirements Document* (24590-WTP-PL-PR-04-0001). This document identifies two samples to be taken from the HLP-VSL-00022 to support criticality analyses. The boundaries for solid fraction sample PT17 are that "The vessel contents are completely mixed for a representative sample." The boundaries for liquid fraction sample PT17 are that "The vessel contents should be completely mixed for a representative sample."

In addition, the distinction between Newtonian and non-Newtonian fluids to support an assessment of the adequacy the PJMs to mix vessel contents has not been adequately and completely addressed. In response to resolution of the PJM mixing issues (24590-WTP-PL-ENG-06-013), the Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear.

> "Distinction between Newtonian and non-Newtonian has been based on anticipated solids concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (less than 20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity."

The lack of clear, consistent, objective design criteria for PJM mixing requirements, which relates the anticipated physical properties in a vessel to specific quantitative mixing requirements, makes it difficult for the Assessment Team to objectively assess the adequacy of the PJM technology and the adequacy of the proposed testing program to resolve mixing issues.

Quantitative mixing criteria related to physical properties are difficult to derive because of the large variability in feeds and lack of comprehensive characterization data. Consequently, a design approach has been pursued providing as robust a mixing system as is practical within the physical limits of the plant systems and utility infrastructure. Conditions that exceed practical design limits may require control of waste feed properties at the tank farms.

The Contractor uses model projections—including the Operational Research Assessment (using WITNESS® software), Tank Utilization Assessments (using the GynSym G2 software), and Steady State Flowsheet (using Aspen Custom Modeler software)—to predict the anticipated WTP flowsheet and production performance and diagnose issues with the design adequacy of the WTP. The Contractor also uses an internally developed Excel-based program to estimate WTP design capability (known as WEBPPS Engineering Mass Balance) and process and mechanical system component calculations to ensure that the WTP design is adequate. These models and calculations all assume that the PT Facility vessels are uniformly mixed within the required time cycle. Based on a review of the CFD model results (24590-PTF-RPT-PR-06-001) and the current identified issues (24590-WTP-RPT-PR-07-002; 24590-PTF-RPT-PR-06-001) with vessel mixing, these projections are optimistic. The *Integrated Sampling and Analysis Requirements Document* (24590-WTP-PL-PR-04-0001) and *WTP Integrated Processing Strategy Description* (24590-WTP-3YD-50-00002) also assume that the vessels are well mixed. The impacts to the production rate and the requirements for process control of WTP have not been evaluated based on limitations of the PJM mixing systems.

However, the impact to the capability of the WTP and the requirements for process control of the WTP have been acknowledged in the currently ongoing capacity improvement design changes whereby alternative mixing approaches, such as in-line mixing of process reagents, is being pursued to reduce dependency on PJM mixing systems for rapid blending.

2.3.6.7 Technology Readiness Level Determination

The PJM system was determined to be a TRL 4 because specific, quantifiable design requirements for the PJM technology have not been established to support testing and design. The definition of the PJM mixing requirements must consider the functional requirements (i.e., safety, environmental, and process control) of the vessels and the anticipated waste characteristics in the vessel.

It is acknowledged that the PJM technology is a viable technology for use in the WTP black cell vessels.

Work associated with the EFRT M-3 IRP relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

Recommendation 7

Clear, quantitative, and documented mixing performance requirements for all PJM mixed vessels in the PT Facility and HLW Vitrification Facility should be established. The requirements should be established for all vessel systems even though only those associated with FRP, HLP, PWD, TLP, and FEP were discussed in this assessment.

These requirements should include requirements from criticality safety, environmental compliance, hydrogen management and mitigation, process control, process operations, and immobilized low-activity waste and immobilized high-activity waste form production. These requirements should be used to assess the adequacy of the design and operation of each of the PJM mixed vessels and provide a basis for the completion of the planned testing work on PJMs planned as part of Issue Response Plan M-3, “Inadequate Mixing System Design.” These requirements should be established jointly with project personnel representing safety, environmental compliance, and process operations, with DOE as owner and operator of the WTP.

Recommendation 8

PJM demonstration testing should be completed. The testing information, supplemented with analysis, should be used to determine the design capability of each PJM mixed vessel and identify any required design changes.

Unresolved Technical Issues

- Process modeling to project the performance of the WTP and confirm design capability should use realistic assumptions on the effectiveness of mixing (both time and efficiency of mixing).

2.3.7 Waste Feed Receipt Process System (FRP)

2.3.7.1 Function of the FRP

The purpose of the FRP is to receive and store waste from the Hanford Site tank farms and, if needed, transfer waste back to the tank farms. Both low-activity and high-level waste can be received. Normally, HLW will be received by the HLP. The waste feed will be pumped from the FRP to processes within the PT Facility.

2.3.7.2 Description of the FRP

The FRP is described in the *System Description for Waste Feed Receipt Process (FRP)* (24590-PTF-3YD-FRP-00001). The FRP includes four feed receipt vessels, a waste feed return pump, and one waste feed transfer pump.

The vessels of the FRP provide feed storage for the PTF, storage for treated LAW from the Treated LAW Concentrate Storage Process System (TCP), high-level waste from HLP, and recycles from the FEP.

The FRP has two pumps. FRP-PMP-00001 is the waste feed return pump, which will be used to return waste to the tank farms, if necessary. FRP-PMP-00002A is the waste feed transfer pump, which will be used to move feed forward into the pretreatment processes (evaporation or ultrafiltration).

The FRP will be used to receive and store waste from the tank farms and transfer feed to PT Facility operations. Three identical pipelines will be available for waste transfers from the tank farms to the PT Facility. The waste feed receipt vessels (FRP-VSL-00002A/B/C/D) can accept tank farm waste if its storage temperature is below 120°F and its solids content is below 5 wt%. These parameters will be confirmed with the Tank Farm Contractor (TFC) before the transfer. Tank farm waste that has a temperature or solids content above these criteria will be sent to the HLW feed receipt vessel (HLP-VSL-00022) because it has a cooling jacket. Waste feed will be pumped from the tank farms at 90 to 140 gpm through one of the three transfer lines. Each transfer pipeline consists of one 3-inch stainless steel pipe contained within a 6-inch carbon steel outer pipe (24590-WTP-ICD-MG-01-019). Transfers will be done every few months during normal operations.

Prior to authorizing a transfer, the TFC will provide samples of the feed to the WTP Contractor. The WTP Contractor will analyze the samples to ensure the waste meets the WTP waste acceptance criteria. Before the transfer to FRP begins, vessel volumes within FRP are verified to ensure enough space is available for the transfer. A main manifold directs the waste to one of the four vessels available for receipt. Valves are aligned to transfer the waste to the first intended vessel. A WTP operator enables the interlock to initiate the transfer. A flush of warm water will be sent from the tank farms to the first FRP vessel to warm the pipe prior to the transfer of tank waste. Once the transfer begins, feed will enter the vessel until a predetermined level setpoint is reached. Then, the valve to the next receiving vessel will be opened, and the valve to the first vessel will be closed. The vertical line between the header and the filled tank will be flushed to prevent solids from clogging the line. This process will continue until the transfer is complete.

Three vessels are required to accommodate an entire million-gallon transfer. After the waste is transferred, the transfer pipeline will be flushed again. The pipeline flush of inhibited water (0.01 M NaOH and 0.011 M $NaNO_2$) will not exceed three times the pipeline volume (7,500 gallons including the pre-transfer flush). The flush will flow from the tank farms source vessel to the receipt vessels. When the motive force provided by the tank farms to transfer the waste and flush is removed (i.e., pump shutdown), the flush remaining in the line will no longer have sufficient head to reach the receipt vessels. Following the flush, any liquid remaining in the pipeline will be drained to PWD-VSL-00043. Level instrumentation in the leak detection pots will detect leakage into the annulus between the transfer line (primary containment) and the outer pipe (secondary containment). If a leak occurs in either the TFC's or the WTP Contractor's transfer/receipt system, the transfer will be interrupted by the TFC or WTP. The TFC master pump shutdown system will be initiated, stopping the tank farm pump. The waste transfer lines are equipped with slow acting valves to prevent a water hammer.

WTP personnel will sample the waste to ensure it is below established criticality specifications per the *Preliminary Criticality Safety Evaluation Report for the WTP* (24590-WTP-RPT-NS-01-001) before it is

sent forward to the PT Facility. Until the vessels are sampled, they will have a "not available for transfers" state (outlet valves closed) pending release by the PT Facility operations manager. The *Integrated Sampling and Analysis Requirements Document* (24590-WTP-PL-PR-04-0001) lists the required analyses and technical drivers for each sample taken from the receipt vessels.

The four waste feed receipt vessels are primarily used to receive waste feed from the tank farms and transfer the waste to either the ultrafiltration feed preparation vessels (UFP-VSL-00001A/B) or the waste feed evaporator feed vessels (FEP-VSL-00017A/B). The working volume of each receipt vessel is 375,800 gallons. Each vessel can receive feed from the tank farms or infrequent transfers from the HLW feed receipt vessel (HLP-VSL-00022) or the FEP (FEP-VSL-00017A/B, FEP-SEP-00001A/B). The waste feed receipt vessels are made of stainless steel and each has a "flanged and dished" type bottom and top head. Vessels FRP-VSL-00002A/B/C/D are located in black cells. Level, density, and temperature instrumentation are installed in each vessel. Each vessel has 12 PJMs for mixing to maintain a uniform concentration of solids for waste feed sampling and transfer and to prevent hydrogen accumulation.

The suction-drive jet pump pair associated with a PJM will be located at least one barometric head (33.9 ft H_2O at 4°C) above the highest liquid level attainable within the vessel. Autosamplers located downstream of the waste feed transfer pump, FRP-PMP-00002A, are used for sampling.

There is a potential for the vessel vapor space to accumulate enough hydrogen to form a flammable mixture. To maintain the hydrogen concentration below the lower flammability limit, forced purge air enters the vessel from the Plant Service Air System. Passive air in-bleed to the vessel via a separate nozzle from the C5V system (from the surrounding black cell) is also provided to purge the vessel vapor space of hydrogen and to aid evaporative cooling for the vessel. The vessels will be maintained at a lower pressure than the surrounding cell. Exhaust gases are sent to the vessel vent header except in a loss of site power incident. If power is lost, the forced purge air supply from the Plant Service Air System is lost, and important-to-safety backup air will be provided via a separate supply header. Each vessel will have internal wash rings to aid in decontamination. Each receipt vessel overflows to the ultimate overflow vessel (PWD-VSL-00033).

2.3.7.3 Relationship to Other Systems

The FRP interfaces with the following major process systems:

- Waste Feed Evaporation Process System (FEP): Vessels FRP-VSL-00002A/B/C/D transfers waste feed to vessel FEP-VSL-00017A/B when sodium content is less than 5 M. Vessels FRP-VSL-00002A/B/C/D receive recycle concentrate from vessels FEP-SEP-00001A/B. Vessels FRP-VSL-00002A/B/C/D receive excess recycles from vessels FEP-VSL-00017A/B.

- HLW Lag Storage and Feed Blending Process System (HLP): Transfer pipelines supply HLW feed to vessel HLP-VSL-00022. Vessels FRP-VSL-00002A/B/C/D receive HLW feed from vessel HLP-VSL-00022. Transfer pipelines and pump FRP-PMP-00001 return HLW solids from vessels HLP-VSL-00027A/B and HLP-VSL-00028 to tank farms. They also return HLW feed from vessel HLP-VSL-00022. Transfers from the HLP are not normal transfers to FRP.

- Plant Wash and Disposal System (PWD): Vessels FRP-VSL-00002A/B/C/D overflow to vessel PWD-VSL-00033. Transfer pipeline flushes drain to vessel PWD-VSL-00043.

- Treated LAW Concentrate Storage Process System (TCP): Vessels FRP-VSL-00002A/B/C/D receive treated LAW concentrate from vessel TCP-VSL-00001 and return concentrate to vessel TCP-VSL-00001. This transfer requires the installation of a jumper and the removal of a blind flange.

- Ultrafiltration Process System (UFP): Vessels FRP-VSL-00002A/B/C/D transfer waste feed to vessels UFP-VSL-00001A/B when sodium concentration is 5 M or greater.

The FRP also interfaces with the Hanford Site tank farms for the receipt (and potential return) of tank waste solutions. The major requirements of this interface include:

- Establishing a permissive/shutdown (interlock) signal for the transfer pumps operated by the TFC, which will incorporate the WTP transfer line leak detection system.

- Receive up to a 1 Mgal batch of LAW feed followed by transfer line flush solution from the TFC.

- Document the volume of waste transfer and flush solution received, and reconcile differences with the transfer volume recorded by the TFC.

- Provide capability for emergency returns of feed to the tank farms followed by transfer line flush solution. Transfer line flush solution is performed at the tank farms and the flush will be received in the FRP.

2.3.7.4 Development History and Status

There has been limited technology testing completed to provide the technical basis for the FRP PJM mixing system design related to suspension and re-suspension in Newtonian vessel systems (most of the data was obtained in early testing of PJM systems at Battelle). The Contractor has relied on the expertise and experience of its subcontractor (AEA Technology) to design PJM systems based primarily on testing and plant operations performed in the United Kingdom. The Contractor has used CFD analysis to further assess the designs. Based on specific recommendations of the EFRT Team, the Contractor has devised a specific technology testing plan as part of the EFRT IRP M3, "Inadequate Mixing System Design," (24590-WTP-PL-ENG-06-0013) to resolve EFRT issues on the adequacy of mixing

CFD analysis completed as early as August 2003 (24590-PTF-RPT-M-03-016) by BNI indicated that the FRP vessels would not adequately mix waste with an assumed set of properties. However, there was some uncertainty in the conclusion because the model run was terminated (due to time constraints) before the mixing simulation reached a steady state condition. This analysis assumed that the waste properties had the following characteristics: 3 wt% solids content, 2.9 g/ml solids density, 22 micron particle size, 1.2 g/ml liquid specific gravity, 2.94 cP viscosity at 25°C with Newtonian fluid characteristics. This analysis indicated that the 8 m/sec PJM drive velocity (normal velocity when the vessel is full) may not be adequate to move the largest particles from the bottom of the vessels, and the 12 m/sec drive velocity (normal velocity when the vessel is full) was recommended by BNI in 2003 to keep large particles in suspension. *(Note: The WTP Contract requirement for solids concentration is 3.8 wt% and the WTP safety basis assumed a 5 wt% solids concentration in the FRP feed.)*

A subsequent FRP mixing system analysis completed in March 2007 (24590-WTP-RPT-PR-07-002) indicated that the PJM designs will not meet the off-bottom suspension criteria at all FRP vessel levels even when the PJM are operated at 12 m/sec discharge velocity. This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be: 1.1 g/ml liquid density, 2.9 g/ml solid density, 210 micron

particle size, and a maximum of 3.8 wt% solids. This analysis completed by BNI in January 2007 also recommended that testing be completed to verify the adequacy of the PJM design for the FRP vessels. The analysis using the BHR Group correlation is based on a steady jet and does not account for fluid viscosity. Thus, the results can only be considered indicative and the system may not perform as well as expected.

Information to support an assessment of the FRP has included characterization of the initial (i.e., first 10 years of operation) Hanford Site tank wastes that will be received in the FRP vessels. The Contractor has completed chemical, physical, and rheological characterization of the initial Hanford Site tank waste compositions that are planned for delivery to the WTP through the FRP and HLP. A summary of this data is provided in Table 2.9 and shows the following:

- The WTP Contract specifications on allowable feed concentrations in the waste are met, based on the tank waste samples provided, with few exceptions.
- Viscosity of the waste is more heavily related to the chemistry than to the solids concentration as suggested by the WTP Contractor in their design basis for rheology (CCN:074567). For example, the AN-102 blended sample has relatively high viscosities (30 cP) at 2 wt% solids.
- Data is very sparse on the waste characteristics required for design, including the relationship between solids content and viscosity and the anticipated particle size. Historical data on additional Hanford Site tank wastes does not appear to have been included in the assessment of the design basis.

Table 2.9. Summary of Tank Waste Characterization Data from WTP Contractor

Tank	Composition Meets WTP Contract	Solids Content (wt%)	Viscosity (cP)	Particle Size Distribution	Reference
AN-102 blended with C-104 leach solutions in ratio of 1 part to two parts, respectively	Sulfate and Cobalt-60 were found to be 110 and 106% above Contract Specification 7 limit, respectively	2 wt%	30.5, 24.9 18.0 cP at 25°, 35°, and 50°C, respectively Fluid characteristics indicate pseudo-plasticity with best curve fit the Oswald Model	Peak 4.1 micron Mode 0 to 12 micron	WTP-RPT-021
AP-101	All Contract Specification 7 limits met Feed diluted to 4.7 M Na prior to characterization	No solids in sample	4.5, 4.4, 2.7, 3.0 cP at 25°, 30°, 50°, and 80°C, respectively	Two peak modes were determined at 5 and 1 micron	WTP-RPT-022
AP-104	All Contract Specification 7 limits met	Not reported	3.47 and 2.36 cP at 25° and 40°C, respectively	Not determined	WTP-RPT-069
AW-101	All Contract Specification 7 limits met	Not determined low solids content	Not determined	Not determined because of low solids content	WSRC-TR-2002-00509
AY-102/C-104	All Contract Specification 7 limits met except TIC at 123% of Contract value Contract Specification 8 limits met	Not reported	4.3 and 3.1 cP at 25° and 40°C, respectively	Solids up to 400-500 micron comprised of particles less than 10 micron, average particle size less than 10 micron	WSRC-TR-2003-00205
AZ-101	All Contract Specification 7 limits met	14 wt% and 45 wt%	2.82 cP at 14 wt% solids and 13 cP at 45 wt%	14.4 % of solids above 16.6 micron, 51% between 4.4 and 16.6 micron and 32% between 1.1 and 4.4 micron and 3% between 0.3 and 1.1 micron	WTP-RPT-048
AN-104	All Specification 7 limit met except U at 102% of limit	Not reported	27 cP	4 micron to > 40 micron	WSRC-TR-2003-00479
AN-107	All Contract Specification 7 limits met except TRU at 130% of Contract value	Not reported	9.4 cP at 25°C and 5.0 cP at 40°C	No information reported on size	WSRC-TR-2003-00210

2.3.7.5 Relevant Environment

Requirements for operation of the FRP are described in the *System Description for Waste Feed Receipt Process* (FRP) (24590-PTF-3YD-FRP-00001). The relevant operational environment for the FRP is:

- Receive and stage LAW and HLW feed from the Hanford Site tank farms.
- Mix and blend low solids containing (<5 wt%) waste solutions to support tank waste characterization activities and release hydrogen gas generated from radiolysis of the tank wastes.
- Mix and blend low solids containing (<5 wt%) waste solutions and transfer these solutions to the FEP and UFP to support process operations.
- Effectively mix and blend a range of waste feed compositions ranging from Newtonian fluid properties to non-Newtonian properties with PJMs.
- Design and fabricate the FRP vessels, which are located in a black cell, to have an operational design life of 40 years.

2.3.7.6 Comparison of the Relevant Environment and the Demonstrated Environment

The Contractor has not conducted any specific testing to validate the adequacy of the FRP PJM design. However, the Contractor has evaluated the design of the PJMs using CFD and other analyses. Based on these results, the Contractor is recommending that testing be completed to assess design adequacy (24590-WTP-RPT-PR-07-002).

As discussed above, the Contractor is relying on CFD analysis to validate the adequacy of the design. This CFD analysis (24590-PTF-RPT-M-03-016) indicates that the PJMs in the FRP vessels may not support the off-bottom suspension mixing requirements. Additional analysis (24590-WTP-RPT-PR-07-002) indicates that the PJM designs will not meet the off-bottom suspension criteria at all FRP vessel levels even when the PJM are operated at 12 m/sec discharge velocity. The Contractor is also recommending (24590-WTP-RPT-PR-07-002) that the size and density of the particles to be delivered to the FRP be reduced compared to the current WTP Contract requirement due to the projected inability of the FRP vessels to suspend solids. The impacts on the tank farms have not been evaluated to deliver reduced size and density of particles in the HLW and LAW feeds.

Based on an evaluation of the relevant environment and documented environment, the Contractor has not established a firm technical basis for the design of the PJMs for the FRP vessels.

2.3.7.7 Technology Readiness Level Determination

The FRP was determined to be a TRL 4 because specific testing to support the adequacy of the mixing design has not been completed. CFD and other computational analyses completed indicated that the PJMs may not be capable of adequately mixing the liquids and solids under normal conditions.

Work associated with the EFRT M-3 IRP relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve

particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

Supporting Recommendation

- An evaluation of the fluids to be received and mixed in the feed receipt vessels (FRP-VSL-00002A/B/C/D) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

2.3.8 HLW Lag Storage and Feed Blending Process System (HLP)

2.3.8.1 Function of the HLP

The primary functions of the HLP are to:

- Receive and stage HLW feed from the Hanford Site tank farms (HLP-VSL-00022).
- Receive and stage HLW intermediate products (i.e., treated solids and Sr/TRU precipitates), and blend Cs concentrates prior to transfer to the HLW Vitrification Facility (HLP-VSL-00027A/B/28).

Secondary functions include the capability to return HLW feed and treated HLW solids back to the Hanford Site tank farms, as required, and to transfer HLW feed to various systems in the PT Facility for treatment. In order to return treated solids back to the tank farms, jumpers need to be installed.

2.3.8.2 Description of the HLP

The HLP is comprised of four vessels as listed in Table 2.10 and described below.

Table 2.10. HLW Lag Storage and Feed Blending Vessels

Vessel Name and Number	Nominal Batch/Working Capacity Kgal	Number of PJMs	Number of Air Spargers for Mixing	Maximum Solids Concentration, wt%	Anticipated Fluid Rheology as identified by the WTP Contractor
HLW Receipt Vessel, HLP-VSL-00022	160	12	0	16.7	Newtonian
HLW Lag Storage, HLP-VSL-00027A	86	8	36	20	non-Newtonian
HLW Lag Storage Vessel, HLP-VSL-00027B	86	8	36	20	non-Newtonian
HLW Feed Blend Vessel, HLP-VSL-00028	81	8	36	20	non-Newtonian

HLW Feed Receipt Vessel (HLP-VSL-00022): HLP-VSL-00022 is designed to receive an uninterrupted transfer of up to 600 m^3 (~160,000 gallons) of HLW tank waste from the Hanford Site tank farms. The received HLW feed is sampled for confirmation of waste acceptance prior to processing in the PT Facility. The HLW feed has a maximum solids concentration of 200 g/L (16.7 wt% solids) as

specified in the WTP Contract. Based upon feed staging analysis, approximately 13% of the waste mass to be received in HLP-VSL-00022 will have a solids concentration of between 13 and 16.7 wt% solids. The balance of the waste will be transferred at a lower solids concentration (average of ~6 wt%).

During waste feed receipt, the PJMs in HLP-VSL-00022 will be operated to provide sufficient mixing within the vessel. Following sampling and characterization, the HLW feed will be transferred for processing to one of two systems: the FEP for concentration if required (expected to be a rare occurrence), or the UFP (normal transfer route) for blending with other process streams prior to solids separation and treatment. The transfer routing will be determined by the current plant status and evaluated on a case by case basis during plant operations. There is also the option to return HLW feed from the HLW feed receipt vessel back to the Hanford Site tank farms via the waste feed return pump, FRP-PMP-00001, in the FRP. This might occur if the waste was determined to be unacceptable for processing in the PT Facility. This is considered an infrequent event because the waste feed is initially sampled in the tank farms feed staging tank and subsequently characterized and certified. The reason for sampling in the HLW feed receipt vessel is that this vessel can be mixed more effectively and efficiently, compared to the nominal 1 Mgal tank farms staging tank and variability in the nominal 160 Kgal batch transfers is anticipated. Thus, the sampling of well blended waste from the HLW feed receipt vessel is important to successful PT Facility operations.

The HLW feed receipt vessel is designed with 12 fluidic PJMs to promote mixing for high-solid content feed. The HLW feed receipt vessel is also fitted with a continuous recirculation line to promote solids suspension within the transfer lines, to mitigate line blockages, and to maintain suction within the line. The HLW feed receipt transfer pump, HLP-PMP-00021, is designed to provide this continuous recirculation capabilities to FEP, FRP, UFP, and waste returns to the tank farms (through the FRP).

Requirements for the sampling and analysis of HLP-VSL-00022 have been established and are summarized in several documents.

- The *Integrated Sampling and Analysis Requirements Document* (24590-WTP-PL-PR-04-0001) identified four sample types to be obtained: solids fraction for criticality (sample PT 17); liquid fraction for criticality (sample PT 17); whole sample for processing evaluation (sample PT 17 a); and liquid fraction for processing evaluation (sample PT 17 a). Each of these samples requires a well-mixed vessel and representative sample.

- The *Preliminary Criticality Safety Evaluation Report for the WTP* (24590-WTP-RPT-NS-01-001) requires that the liquid and solid phase of the received waste be sampled to verify that the Pu concentration of the waste is below specific criticality limits. These samples require that the vessel contents be completely mixed and a representative waste sample obtained.

- The *WTP Integrated Processing Strategy Description* (24590-WTP-3YD-50-00002) further defines the requirements for process control of HLP-VSL-00022 and identifies requirements for analysis (however, the specific analyses are not defined) of the sample material including:

  - The facility shall be designed and operated in a manner that prevents nuclear criticality and complies with the requirements of DOE O 420.1B, *Facility Safety*.

  - Analyze samples or use existing information to verify compliance with WTP permits and safety authorization basis.

HLW Lag Storage Vessels (HLP-VSL-00027A/B): HLP-VSL-00027A and HLP-VSL-00027B are used to store the sludge slurry concentrates from the UFP, including Sr/TRU precipitate from treatment of the LAW Envelope C, and washed and leached sludge. These intermediate sludge slurry products are received, segregated, and staged separately in one of the two HLW lag storage vessels (HLP-VSL-00027A or HLP-VSL-00027B). Sampling is done once the vessels are filled and locked out to confirm the composition of the vessel for blending purposes. The requirements for sampling and analyses of these vessel contents are discussed in further detail in 24590-WTP-PL-PR-04-0001.

The nominal operating volume of each HLW lag storage vessels is 86,000 gallons. Transfers from vessels UFP-VSL-00002A or UFP-VSL-00002B will average 10,000 gallons. Because these vessels are designated as non-Newtonian (and thereby require mixing by both PJMs and spargers to release hydrogen gas generated from radiolysis), the PJMs (and spargers) are continually operated unless the vessel contents are below a minimum operating level. Based on nominal waste treatment rates it will take about 20 days of processing in the UFP to fill a lag storage vessel. When required, the HLW intermediate products in the lag storage vessels are transferred to the HLW feed blend vessel (HLP-VSL-00028) and blended with Cs concentrate from the CNP.

Slurry from the lag storage vessels can be returned to the Hanford Site tank farms via the waste feed return pump, FRP-PMP-00001. The return of solids is considered an infrequent event, requiring the installation of jumpers.

For operational flexibility, there is the option to also use vessel HLP-VSL-00027B for HLW feed blending prior to transfer to the HLW Vitrification facility. In this case, the HLW feed blending vessel, HLP-VSL-00028 may be used as a lag storage vessel. Transfer lines from the CNP and future Cs/Sr capsule treatment facilities (to be located outside the PT Facility) are also available to vessel HLP-VSL-00027B in order to achieve this blending function.

The HLW solids transfer pump, HLP-PMP-00017A, is connected to vessel HLP-VSL-00027A, and HLP-PMP-00017B is connected to vessel HLP-VSL-00027B. Both pumps have the capability to transfer to the FRP and to the Hanford Site tank farms, while pump HLP-PMP-00017B has the ability to transfer to the HLW Vitrification Facility. For transfers to the Hanford Site tank farms, pump HLP-PMP-00017A/B will be operated in series with pump FRP-PMP-00001.

Requirements for the sampling and analysis of HLW lag storage vessels are summarized in 24590-WTP-PL-PR-04-0001. These requirements involve characterization for process control and process operations planning. This sampling and analysis require a well mixed vessel and representative sample.

HLW Feed Blend Vessel (HLP-VSL-00028): HLP-VSL-00028 is used to prepare and stage HLW feed from the PT Facility to the HLW Vitrification Facility. The treated solids may be blended with a diversity of high-level wastes including Sr/TRU precipitate slurries and the Cs concentrates recovered from the LAW treatment process. There is also the capability to treated Cs/Sr slurry from the Hanford Cs/Sr capsules. The nominal operating volume of the HLW feed blend vessel is 81,000 gallons. Transfers to the HLW Vitrification Facility are nominally 4,500 gallons and occur every 36 hours. Because the HLW feed blend vessel is designated as non-Newtonian (and thereby require mixing by both PJMs and spargers to release hydrogen gas generated from radiolysis), the PJMs (and spargers) are continually operated unless the vessel contents are below a minimum operating level.

HLW feed blending will occur primarily in vessel HLP-VSL-00028. HLW feed blending depends on feed delivery scheduling and the stage of processing at the time of blending. The HLW feed blend vessel is fitted with two HLW feed pumps, HLP-PMP-00019A/B. One pump is used as a backup pump during repair and maintenance. Limitations of heat duty on the HLW blended feed may restrict the addition rate of some intermediate products. Cs concentrate contains considerable amounts of radiolytic Cs isotopes,

which generate high-heat duties from radiolytic decay. In addition, to minimize the production of immobilized high-level waste glass, limitations on the addition of Sr/TRU precipitate is desired.

Requirements for the sampling and analysis of HLW feed blend vessel are summarized in 24590-WTP-PL-PR-04-0001. These requirements involve characterization for process control and process operations planning. This sampling and analysis requires a well-mixed vessel and representative sample.

24590-PTF-M0D-M40T-00002 provides the following mixing requirements for the HLP vessels (Table 2.11).

Table 2.11. Summary of Mixing Requirements for the HLP Vessels

Vessel	Mixing Requirements	Viscosity cP	Temperature °F	Solids Concentration wt%
HLP-VSL-00022	• Prevent solids accumulation and facilitate hydrogen evolution • Provide representative sample to support waste acceptance criteria (95% confidence level)	1 - 94	50 - 190	0.1 - 20
HLP-VSL-00027A	• Prevent solids accumulation and facilitate hydrogen evolution • Mixing to support Quality Assurance Requirements Document (QARD) sampling requirements; Solids concentration gradient should not deviate more that 1% vertically and radially	5 - 230	50 - 113	15 - 25
HLP-VSL-00027B	• Prevent solids accumulation and facilitate hydrogen evolution	5 - 230	50 - 113	15 - 25
HLP-VSL-00028	• Prevent solids accumulation and facilitate hydrogen evolution • Mixing to support QARD sampling requirements; Solids concentration gradient should not deviate more that 1% vertically and radially	5 - 230	50 - 113	15 - 25

2.3.8.3 Relationship to Other Systems

There are three primary interfaces with the HLP, HLP-VSL-00022, HLP-VSL-000027A/HLP-VSL-00027B, and HLP-VSL-000028. Each of these interfaces have their own interfaces as follows:

- HLP-VSL-00022 has the following interfaces:
  - Hanford Site tank farms for the receipt of HLW waste feed. The feed will be delivered in batches up to 600 m^3 (160 Kgal), including flush volume. Each batch will have a solids concentration no greater than 200 g/L and no less than 10 g/L.
  - FRP, FEP, and UFP for further processing of the HLW slurry.

- HLP-VSL-000027A/HLP-VSL-00027B have the following interfaces:
  - UFP for the receipt of washed and leached HLW sludge and Sr/TRU precipitate.
  - HLP-VSL-00028 for the transfer of treated HLW slurry to support waste feed blending.
- HLP-VSL-000028 has the following interfaces:
  - HLP-VSL-00027A/HLP-VSL-00028B for the receipt of washed and leached HLW sludge and Sr/TRU precipitate.
  - CNP-VSL-00004 for the receipt of Cs concentrate.
  - External potential future facility for the receipt of Cs and Sr slurries generated from the treatment of the Hanford Cs and Sr capsules.
  - HLW Vitrification Facility melter feed preparation vessels.

2.3.8.4 Development History and Status

The development history of the HLP is directly related to the design of the fluid mixing systems (PJMs and spargers) and blending of the major process streams. The development of the mixing systems will be addressed in the broad categories of Newtonian (shear insensitive) fluid mixing and non-Newtonian (shear sensitive) fluid mixing.

Newtonian Fluid Mixing Development: The Contractor has not collected any testing data in prototypic PJM test systems to demonstrate the mixing of prototypic Newtonian slurries. The Contractor is relying on CFD analysis to validate the adequacy of the design.

The WTP Contractor has prepared an IRP for EFRT issue M-3, "Inadequate Mixing System Design," (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries.

Non-Newtonian Fluid Mixing Development: Extensive non radioactive simulant testing has been conducted by the WTP Contractor to test the PJM and vessel design concepts for wastes containing high-solid concentrations. These studies were focused on establishing the design and operational requirements for the vessels that are nominally referred to as containing non-Newtonian wastes. A summary of the extensive technology testing information is provided in Section 2.3.6.4.

2.3.8.5 Relevant Environment

Requirements for operation of the HLP are described in the *System Description for HLW Lag Storage and Feed Blending (HLP)* (24590-PTF-3YD-HLP-00001). The relevant operational environment for the HLP is:

- Receive and stage HLW feed from the Hanford Site tank farms.
- Receive, mix, and stage HLW intermediate products; treated solids and Sr/TRU precipitates, and treated solids and Cs concentrates, prior to transfer to the HLW Vitrification Facility.
- Effectively mix and blend a range of waste feed compositions ranging from Newtonian fluid properties to non-Newtonian properties with PJMs.

- Transfer solids slurries between the HLP vessels and other PT Facility process vessels.
- Transfer solid slurries between the HLP vessels and the HLW Vitrification Facility.

2.3.8.6 Comparison of the Relevant Environment and the Demonstrated Environment

HLW Feed Receipt Vessel (HLP-VSL-00022): As summarized above, testing to demonstrate prototypic mixing in the HLW feed receipt vessel has not been completed. And as summarized in Section 2.3.7.6, the mixing requirements for HLP are not clearly and completely defined.

As assessment of the properties of the as-received HLW, feed was provided in CCN:074567 to provide a basis for design. This assessment evaluated tank waste characterization data from Hanford tanks AZ-101, AZ-102, C-104, and AY-102/C-106. This assessment showed that if the solids concentration is maintained below 200 g/L (equivalent to 16.6 wt% solids), the WTP Contract specification upper limit, that the rheological properties are bounded by a yield stress of 1 Pa and a viscosity of 10 cP. However, if the tank waste concentration increased to 300 to 400 g/L, then the rheological properties could increase to yield stress of 3 to 4 Pa and a viscosity of 30 to 35 cP. This assessment concluded that at less than 200 g/L the waste could be considered Newtonian. This assessment did not evaluate shear stress and shear rate information because of lack of availability of information. Limited shear rate and stress information is available on pretreated HLW tank waste compositions. Data provided in 24590-101-TSA-W000-0004-114-00019 indicated that washed sludge compositions at concentrations of 15 to 22 wt% exhibit Bingham Plastic rheological properties.

24590-PTF-M0D-M40T-00002 provides the following mixing requirements for the HLP vessels (Table 2.11). These design requirements, which are used as a basis for the specification of the PJM by AEA Technology, indicate that the HLP vessels would exhibit Newtonian waste properties based on viscosity and solids content.

CFD analysis completed as early as August 2003 (24590-PTF-RPT-M-03-016) indicated that the HLP-VSL-00022 would not adequately mix waste with an assumed set of properties. This analysis was a steady state simulation. This analysis assumed that the waste properties had the following characteristics: 3 wt% solids content, 2.9 g/ml solids density, 22 micron particle size, 1.2 g/ml liquid specific gravity, and 2.94 cP viscosity at 25°C with Newtonian fluid characteristics. This analysis indicated that the 8 m/sec PJM drive velocity (normal velocity when the vessel is full) may not be adequate to move the largest particles from the bottom of the vessels and the 12 m/sec drive velocity (normal velocity when the vessel is full) is recommended to keep large particles in suspension.

A subsequent HLP mixing system analysis completed in March 2007 (24590-WTP-RPT-PR-07-002) indicated that the PJM design for HLP-VSL-00022 would not meet the off-bottom suspension criteria for HLP-VSL-00022 even when the PJMs are operated at 12 m/sec discharge velocity. This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be 1.1 g/ml density of liquid, 2.9 g/ml density of solid, 210 micron mean particle size, and a maximum of 16.68 wt% solids. The analysis using the BHR Group correlation is based on a steady jet and does not account transients such as the PJM drive, vent, and re-flood modes of operation. Thus, the results can only be considered indicative and the system may not perform as well as projected.

The fabrication of HLP-VSL-00022 has been suspended pending the resolution of the issues associated with the mixing of fluids in this vessel.

2.3.8.7 Technology Readiness Level Determination

The HLP-VSL-00022 was determined to be TRL 4 because the technology requirements have not been clearly formulated, and the technology design has been determined by the WTP Contractor to not support basic requirements.

The HLP-VSL-00027A, HLP-VSL-00027B, and HLP-VSL -00028 were determined to be TRL 5 because of the extensive testing completed by the WTP Contractor to establish the technology requirements for mixing in the vessels. Other requirements of these vessels have not been demonstrated including the ability of these vessels to effectively mix washed and leached sludge solids. In addition, testing of the PJMs is still underway to assess PJM overblow with clay simulants and impacts of anti-foam on gas retention and release.

However, overall the HLP was determined to be a TRL 4 because of the lower score of HLP-VSL-00022.

Work associated with the EFRT M-3 IRP relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

Supporting Recommendation

- An evaluation of the fluids to be received and mixed in the HLW feed receipt vessel (HLP-VSL-00022) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

2.3.9 Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD)

2.3.9.1 Function of the PWD and RLD

The primary function of the PWD and RLD is to receive washes and recycle streams from other vessels in the PTF, and washes and selected recycle streams from the HLW Vitrification Facility, LAW Vitrification Facility, and Analytical Laboratory.

2.3.9.2 Description of the PWD and RLD

The PWD and RLD are described in the *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD* (24590-PTF-3YD-PWD-00001). The PWD receives effluent for storage, neutralization, and transfer to the evaporation system. The effluent includes plant wash from PT Facility vessel sumps, acidic, and alkaline effluent generated during pretreatment operations, and solids wash permeate from ultrafiltration. PWD also receives plant wash from the HLW and LAW Vitrification Facilities, HLW SBS condensate as well as liquid wastes from the Analytical Laboratory. The PT Facility RLD receives evaporator overhead condensate for recycle as process condensate and LAW caustic scrubber waste for transfer to the Liquid Effluent Retention Facility (LERF), Effluent Treatment Facility (ETF), or back to evaporation depending on sample analysis.

Excess process condensate is also transferred to LERF/ETF. Major plant items for these systems include vessels, breakpots, pumps, and sumps.

2.3.9.3 Relationship to Other Systems

The PWD and RLD interface with virtually all process systems in the PT Facility and the recycle streams from the LAW Vitrification and HLW Vitrification Facilities. The primary interfaces are described in Table 2.12. The system description for the PWD and RLD (24590-PTF-3YD-PWD-00001) defines a more detailed breakdown of the interfaces and will not be repeated here.

Table 2.12. Summary of Major Vessel in the PWD and RLD

Vessel Number	Common Name/Function	Vessel Material of Construction	Number of PJMs	Nominal Vessel Capacity, kgal
PWD-VSL-00015	Acidic/Alkaline Effluent Vessels Receive and store Cs in exchange column rinses, Cs evaporator condensate and caustic ultrafilter cleanings. Can also receive, neutralize, and store ultrafiltration solids wash, caustic leach, and nitric acid cleanings. Vessel contents are neutralized and sampled prior to transferring into the process. Transfer to FEP feed vessels. Vessel operates in parallel with PWD-VSL-000016.	316L	8	80
PWD-VSL-00016	Acidic/Alkaline Effluent Vessels Receive and store Cs in exchange column rinses, Cs evaporator condensate and caustic ultrafilter cleanings. Can also receive, neutralize, and store ultrafiltration solids wash, caustic leach, and nitric acid cleanings. Vessel contents are neutralized and sampled prior to transferring into the process. Transfer to FEP feed vessels. Vessel operates in parallel with PWD-VSL-000016.	316L	8	80
PWD-VSL-00033	Ultimate Plant Overflow Vessel Receive and transfer laboratory drains and flushes, other line drains, pit sump and PT Facility vessel overflows. Transfer to other PWD-VSL-00044 vessels.	316L	8	15
PWD-VSL-00043	HLW Effluent Transfer Vessel Receive and store waste from HLW Vitrification Facility plant sump area line drains. Transfer to PWD -VSL-00044.	316L	8	15
PWD-VSL-00044	Plant Wash and Disposal Vessel Plant Wash Vessel-Receive and store plant washes, sumps, and other small miscellaneous streams. The vessel contents are neutralized to ensure proper PH in downstream processing. Primary interface is with the FEP feed vessels.	316L	8	60

Table 2.12. Summary of Major Vessel in the PWD and RLD

Vessel Number	Common Name/Function	Vessel Material of Construction	Number of PJMs	Nominal Vessel Capacity, kgal
PWD-VSL-00045	C2 Floor Drain Collection Vessel Receive C2 area wastes, sample wastes, and transfer wastes. Vessel contents are sampled and transferred to BOF-NLD-TK-00001 or to RLD-VSL-00017A/B	316L	NA	2.4
PWD-VSL-00046	C3 Floor Drain Collection Vessel Receive C3 area wastes, sample wastes, and transfer wastes. Vessel contents are sampled and transferred to PWD-VSL-000045 or to RLD-VSL-00017A/B	316L	NA	2.4
RLD-VSL-00017A/B	Alkaline Effluent Vessels Receive and store caustic waste from the LAW vitrification facility offgas scrubber, process condensate area sump, and the C3 drain. Vessel is sampled to determine final destination, recycles either back into process or eventual transfer to LERF/ETF. Normally transfers to process condensate tanks.	316L	4	25
RLD-TK-00006A/6B	Process Condensate Tank Store evaporator overhead condensate and waste from RLD-VSL-00017A/17B. Provide hold point for material prior to transfer to LERF/ETF. Provide storage for process condensate recycled back to process.	316L	NA	265

2.3.9.4 Development History and Status

Active waste processing does not occur in the PWD and RLD. However, the mixing of process streams and neutralization of process streams do occur in selected vessels within the PWD. Therefore, the Contractor has conducted initial mixing studies to examine the interaction of process streams. Additional areas of technology are associated with the PJMs and their ability to effectively blend process fluids and suspend solids.

As described in Section 2.3.6, there has been no specific testing of PJM systems with low solids containing fluids. In response to issues raised by the EFRT (CCN:132846), the WTP Contractor has prepared an IRP for EFRT issue M-3, "Inadequate Mixing System Design," (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain low solids Newtonian slurries.

A number of mixing studies have been completed to assess the interaction of process streams. An identification of the major reports and conclusions are summarized below.

- *Mixing of Process Heels, Process Solutions, and Recycle Streams: Results of the Small-Scale Radioactive Tests* (*PNWD-3029)*: A precipitate formed when the AN-107 LAW sample was mixed with the solution generated by washing the AN-107 entrained solids. This precipitate was rich in Al, bismuth, iron, manganese, and silicon. Solids formation was also observed upon mixing the AN-107 sample with the AW-101 sample and upon mixing the AN-107 sample with the C-104 sludge leach/ wash solution. During plant operations, mixing of these solutions should be avoided to prevent formation of solids.
- *Mixing of WTP Process Solutions (PNWD-3341):* In selected combinations of test solutions, precipitates were observed. In addition, thermodynamic modeling indicated many other solutions to be saturated or oversaturated in selected components. If the modeling is correct, slow precipitation of solids, even after the filtration step in the WTP, may occur, with potential impacts to downstream operations such as IX. Furthermore, this precipitation of solids may lead to an increase in the amount of material reporting to HLW vitrification. Alternatively, the poor agreement between the Environmental Simulation Program (ESP) modeling conclusion and the observation of the mixed process solution may reveal limitations in the predictive capability of the ESP model or the analytical results.

The EFRT report (CCN:132846) identified issues on process operating limits and gelatin of process streams. These were:

Process Operating Limits Not Completely Defined

"Many of the process operating limits of the WTP unit operations have not yet been determined.

Much of the research and technology work for the WTP has been to validate the process equipment design. This type of work is required, but is certainly not adequate to completely develop a process. The key variables that affect the efficiency of each process must be known. Then, the upper and lower bounds of each process variable must be understood. Finally, possible and unexpected interactions of these variables must be understood. Without this more complete understanding of each process, it will be difficult or impossible to define a practical operating range.

The EFRT recommends additional testing be performed to expand the understanding of WTP process capability and to define practical process operating limits for each unit operation."

Gelation/Precipitation

"Some of the feeds to the leaching operation will contain significant amounts of aluminum and other materials that could precipitate. There is the possibility aluminum gel will form in the leach tank itself or in other streams from the leaching operation if unfavorable leaching conditions occur."

The Contractor has prepared ***Error! Unknown document property name.*** (24590-WTP-PL-ENG-06-0016). The work planned as part of this IRP (which is in progress) includes:

- Evaluation of the completeness of data on the performance of each process operation as a function of feed characteristics/composition and process operating parameters (temperature, flow rate, pH, and so on) at the process operating limits.

- Identification of the conditions that cause degradation of process operation performance so that those limitations can be documented and those conditions can be avoided during operations.

- Review of the process operating limits for the anticipated range of operating modes including (a) normal processing steps; (b) startup, shutdown, and standby modes during transitions between those operating modes; and (c) anticipated off-normal conditions such as a loss of power.

- Determination of the combination of feed characteristics/compositions and process operating parameters that lead to precipitation or gelation reactions that either plug pipelines or degrade system performance due to ultrafiltration and leaching operations. Determination of the conditions during leaching which are likely to contribute to gelation or precipitation downstream.

- Identification where chemical line plugging due to gelation or precipitation of process streams would be most likely to occur. Development of strategies to reverse or mitigate line plugging if it were to occur. Identify design features or operating techniques to implement those strategies.

2.3.9.5 Relevant Environment

Requirements for operation of the PWD and RLD are described in the *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD* (24590-PTF-3YD-PWD-00001). The relevant operational environment for the PWD/RLD is:

- Receive and neutralize a variety of WTP process streams.
- Mix and sample process streams for subsequent to support planning for subsequent treatment.
- Store process fluids containing solids, mix process fluids containing solids and liquids, and ensure effective release of hydrogen gas and support process operations.

2.3.9.6 Comparison of the Relevant Environment and the Demonstrated Environment

Initial mixing studies have been performed to assess the mixing of wastes and process streams. Very limited testing has been completed to assess the interaction of secondary wastes from process system effluents. This is because the PT process flowsheet has not been completely developed. The work associated with the IRP M6/P4 (24590-WTP-PL-ENG-06-0016) will provide the first major assessment of the impacts of process chemistry on planned operations in the PT flowsheet.

An assessment in March 2007 (24590-WTP-RPT-PR-07-002) of the ability of the PWD and RLD vessels has identified that PWD-VSL-00044 will fail the off-bottom suspension criteria and that PWD-VSL-00033 and PWD-VSL-00043 will only marginally meet the off-bottom suspension criteria for 50/50 mixing (condition that assumes that one half of the PJMs are operating at a time). This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be density of liquid 1.1, density of solid-2.9, particle size 210 micron. The solids concentration was 5 wt%. This analysis recommended that the discharge velocity of the PJMs be increased from 8 m/sec to 12 m/sec. Testing was also recommended to verify the adequacy of the PJMs in the aforementioned vessels.

2.3.9.7 Technology Readiness Level Determination

The equipment technology associated with the RWD and RLD has been determined to be a TRL 4 due to the unresolved issues on the PJMs; i.e., the lack of definition of clear requirements for PJM performance and the unresolved issues in the mixing of low viscosity solids solutions as discussed in Section 2.3.6. An assessment in March 2007 (24590-WTP-RPT-PR-07-002) of the ability of the PWD and RLD vessels has identified that PWD-VSL-00044 will fail the off-bottom suspension criteria and that PWD-VSL-00033 and PWD-VSL-00043 will only marginally meet the off-bottom suspension criteria for 50/50 mixing (condition that assumes that one half of the PJMs are operating at a time).

Initial studies on the mixing of process streams such as would occur in the PWD vessels has been completed. These studies indicate that careful control of the pretreatment process is critical to ensuring that solids will not be created which could lead to adverse process performance. Plans for the resolution of a number of potential mixing issues are in place as part of IRP M6/P4, "Process Limits Not Completely Defined/Gelation Precipitation" (24590-WTP-PL-ENG-06-0016).

Work associated with the EFRT M-3 IRP relating to inadequate mixing system design will involve performing a number of scaled tests to investigate the hydrodynamic phenomena involved with PJM operation. Tests will be performed at scales ranging from approximately 1/10 to 1/2 (based on vessel diameter), with single and multiple PJMs in operation in the tanks. A number of these tests will involve particle-laden fluids so that suspension, entrainment, and re-suspension issues can be investigated. The tests will be extensively instrumented to provide a wealth of quantitative data on the fluid and particle dynamics involved with PJM operations (24590-PTF-TSP-RT-06-007).

3.0 Summary, Recommendations, and Supporting Recommendations

3.1 Summary

The TRA for the PT Facility determined that nine systems were CTEs:

- Cesium Nitric Acid Recovery Process System (CNP)
- Cesium Ion Exchange Process System (CXP)
- Waste Feed Evaporation Process System (FEP)
- Treated LAW Evaporation Process System (TLP)
- Ultrafiltration Process System (UFP)
- Pulse Jet Mixer (PJM) system
- Waste Feed Receipt Process System (FRP)
- HLW Lag Storage and Feed Blending Process System (HLP)
- Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD)

The results of the TRL assessment for each of the CTEs are summarized in Table 3.1. Consistent with NASA and DoD practices, this assessment used TRL 6 as the level that should be attained before the technology is incorporated in the WTP final design. The CTEs were not evaluated to determine if they had matured beyond TRL 6.

3.2 Recommendations

Based upon the results of this assessment, the following recommendations for specific technologies are made:

Recommendation 1

Design activities associated with the CNP should be discontinued until: (1) a reassessment of the design and operational requirements for the CNP is completed; (2) the engineering specification for the CNP is revised to reflect operational conditions; and (3) the technology concept, which includes the process equipment and control system, is demonstrated through integrated prototypic testing.

Rationale

The design concept for the CNP evaporator has not been previously used in radioactive operations for the recovery of nitric acid, or proven by the Contractor in testing. Engineering calculations for the system design do not represent the variable feed compositions from the CXP and resultant product composition anticipated in the CNP. The CNP nitric acid product will likely require compositional adjustment to support subsequent reuse as an elution agent. The proposed continuous operation of the CNP will not accommodate this required chemical adjustment. Thus, the system as conceptualized appears to be undersized and may not support the waste treatment rate requirements of the PT Facility. This process design deficiency appears to be the result of the "Pretreatment

Reconfiguration" studies that removed two CNP feed vessels and two CNP acid product vessels from the plant flowsheet.

Recommendation 2

The CNP should be functionally tested prior to installation in the black cell. The testing should include: testing with representative process feed compositions; verifying the process control system concept; verifying the ability to control and monitor the composition of the nitric acid product; demonstrating the cesium decontamination factor of 5 million; and demonstrating the ability to adequately decontaminate the demister pads using the sprays installed in the separator vessel.

Rationale

The CNP is not planned to be tested until cold commissioning. The CNP will be installed in a black cell and will be very difficult to modify after installation because of accessibility. Testing prior to installation will demonstrate the adequacy of the design and minimize post-installation modifications.

Recommendation 3

Prototypic equipment testing should be completed prior to continuing design of the hydrogen venting subsystem (nitrogen inerting and hydrogen gas collection piping system, and control system) for removing hydrogen and other gases from the cesium IX columns to demonstrate this design feature over the range of anticipated operating conditions.

Rationale

Integrated testing of all CXP technology components has not been completed. Major components not tested include the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns, and the capability to remove 99% by volume of the spherical RF resin from a prototypic IX column. The hydrogen venting system is a first-of-a-kind engineered design that is essential to safe operations of the CXP. Without proper functioning of this system, the CXP may not meet its required waste treatment rate performance objectives.

Alternatively, the project should consider re-designing (and testing) the hydrogen venting subsystem for the IX columns in order to simplify the system. For example, a small recycle stream from the IX columns to the feed vessel (CXP-VSL-00001) could be used to vent gases from the columns. The recycle stream could be controlled through the use of orifice plates and stop valves for isolation.

Recommendation 4

The adequacy of the design concept for CXP-VSL-00001 should be reevaluated and a determination made if this vessel should be modified to include mixing, chemical addition, and heating/cooling to mitigate anticipated process flowsheet issues with precipitation of solids in the CXP feeds.

Rationale

Bechtel National, Inc. engineering studies conducted in 2005 and 2007 indicate that precipitation of sodium oxalate and gibbsite solids will occur following filtration. The capability of the CXP to effectively treat feeds that contain freshly precipitated sodium oxalate and gibbsite solids is not known. Understanding of the dissolution and precipitation kinetics for sodium oxalate and gibbsite is lacking. The morphology of freshly precipitated sodium oxalate is not completely understood.

The CXP-VSL-00001 has no capability for blending solutions or suspending solids. Flowsheet modeling indicates that solids are likely to precipitate if chemical adjustments are not made to the vessel. The CXP-VSL-00001 has no capability for chemical adjustments to reduce/mitigate the solids concentration in cesium IX feed or dissolve/remove solids. It is not clear that the CXP-VSL-00001 vessel design is adequate to perform its required function and support the waste treatment capacity requirements of the PT Facility.

Recommendation 5

Development and testing at a laboratory-scale with actual wastes, and at an engineering-scale with simulants, should be completed in prototypical process and equipment testing systems to demonstrate all detailed flowsheets for the UFP prior to final design. The testing should validate the scaling methodology for mixing, chemical reactions, and filter surface area sizing; determination of process limits; and recovery from off-normal operating events.

Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-12, "Undemonstrated Leaching Process," and WTP Baseline testing of the Oxidative Leaching Process.

Rationale

Previous DOE evaluations (D-03-DESIGN-05) have been completed on the adequacy of the UFP process chemistry and ultrafilter sizing. This assessment concluded that the WTP flowsheet was not adding sufficient sodium hydroxide to support the dissolution of aluminum in the HLW sludge and the ultrafilter surface area was undersized by a factor of about 2.6. Partial planning is in place by the Contractor to conduct technology testing to provide the technical basis for the ultrafiltration flowsheet and equipment design.

Recommendation 6

Evaluation of a vertical modular equipment arrangement for the UFP filter elements for increasing the filter surface area should be continued. The design configuration (currently proposed horizontal or vertical orientation of the filters) that has the highest probability of successfully achieving performance requirements should be thoroughly tested in high fidelity, prototypical engineering-scale tests using simulants that represent a range of tank waste compositions. Testing scope should include all filtration system operations, process flowsheets (caustic and oxidative leaching and strontium/transuranic precipitation), high-temperature filtration, and filter back pulsing, cleaning, draining, and replacement. Based on the results of this testing, a design concept (either the horizontal arrangement proposed by the Contractor or the vertical arrangement conceptualized by Energy*Solutions*) should be selected for final design.

Rationale

A review and assessment of a proposed modified ultrafiltration system design was conducted by the Contractor. This design concept was based on deploying five filter elements (two 10 ft sections and three 8 ft sections) in a nominally horizontal arrangement as a single fabricated unit. The expert review team advised that:

- The proposed new arrangement for the ultrafilter with five modules connected in series may not provide sufficient drainage, and may cause problems with residual slurry solids buildup in the lower tubes of each module.

- The need to remove and discard a complete five-module filter system because of a blockage or partial blockage, and its replacement with a new unit, may be both lengthy and costly.
- An alternate vertical arrangement of filter modules was strongly recommended by the reviewers. Such an arrangement would trap residual solids within the tubes themselves and have the potential to allow the removal of individual modules or tube bundles.

Recommendation 7

Clear, quantitative, and documented mixing performance requirements for all PJM mixed vessels in the PT Facility and HLW Vitrification Facility should be established. The requirements should be established for all vessel systems even though only those associated with FRP, HLP, PWD, TLP, and FEP were discussed in this assessment.

These requirements should include requirements from criticality safety, environmental compliance, hydrogen management and mitigation, process control, process operations, and immobilized low-activity waste and immobilized high-activity waste form production. These requirements should be used to assess the adequacy of the design and operation of each of the PJM mixed vessels and provide a basis for the completion of the planned testing work on PJMs planned as part of Issue Response Plan M-3, "Inadequate Mixing System Design." These requirements should be established jointly with project personnel representing safety, environmental compliance, and process operations, with DOE as owner and operator of the WTP.

Rationale

The lack of requirements for mixing performance of each PJM mixed vessels does not provide a basis for:

- The Contractor's mixing design for the vessels and PJMs.
- DOE's assessment, as owner and operator of the WTP, of the adequacy of the WTP to achieve safety and operational requirements.
- The Contractor's planning and conduct of a technology testing program to generate PJM mixing test information to support design decisions (see Recommendation 8).

Recommendation 8

PJM demonstration testing should be completed. The testing information, supplemented with analysis, should be used to determine the design capability of each PJM mixed vessel and identify any required design changes.

Note: This planned testing work is in the WTP Baseline as part of the testing identified in M-3, "Inadequate Mixing System Design."

Rationale

The Contractor has developed a testing program on the PJMs to assess the adequacy of the design and operation of each of the PJM mixed vessels.

3.3 Supporting Recommendations

The following supporting recommendations are made by the Assessment Team. These recommendations supplement the major recommendations presented in the previous section

1. The specific gravity operating limit for controlling the concentrated cesium eluate in the CNP separator to a maximum of 80% saturation should be re-evaluated. Based on the WTP Contractor's plan to neutralize cesium concentrate in the separator, and thereby create solids, this operating constraint may not be required.

2. The engineering specification for the CNP should be modified to include (1) the estimated variable feed composition and (2) factory acceptance testing to demonstrate removal and installation of the demister pads from the separator vessel.

3. The Contractor should reassess the corrosion evaluations for the CNP vessels and piping based on the operating conditions of the system.

4. Testing of spherical RF resin should be conducted to: (1) assess physical degradation for irradiated resin samples; (2) assess effects from anti-foaming agent and separate organics present in the feed to the CXP; and (3) assess the impact of particulates on IX column performance.

5. All currently planned testing and documentation of test results for spherical RF resin should be completed. (*Note: This planned work is in the WTP Baseline.*)

6. Additional research should be performed to attain a higher degree of understanding of the dissolution and precipitation kinetics for sodium oxalate.

7. The engineering specification for the IX columns should be revised to incorporate the use of spherical RF resin and any design modifications resulting from closure of the External Flowsheet Review Team recommendations for the CXP.

8. The engineering specification for the CXP should be modified to include factory acceptance testing of the IX column to demonstrate that the system is capable of removing greater than 99% by volume of resin from the IX column, upon completion of the resin removal mode, using a maximum volume of 7,500 gallons of water to displace the resin.

9. The strategy and method to scale the ultrafiltration processes (mixing, chemical reaction, and filter surface area) to predict performance of the ultrafiltration system should be established to ensure a high-fidelity UFP engineering-scale test platform and support useful interpretation of the testing results.

10. Process modeling to project the performance of the WTP and confirm design capability should use realistic assumptions on the effectiveness of mixing (both time and efficiency of mixing).

11. An evaluation of the fluids to be received and mixed in the feed receipt vessels (FRP-VSL-00002A/B/C/D) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

12. An evaluation of the fluids to be received and mixed in the HLW feed receipt vessel (HLP-VSL-00022) should be completed to ensure that the requirements for actual waste conditions are known and the mixing concept design is adequate.

Table 3.1. Technology Readiness Level Summary for the Pretreatment Critical Elements

Critical Technology Element and Description	Technology Readiness Level	Rationale
Cesium Nitric Acid Recovery Process System (CNP) The function of the CNP is to treat Cs eluate by evaporation from the CXP to recover and recycle the nitric acid. The CNP is an integral part of the CXP operating concept. The recovered nitric acid is used for ion exchange column elution. The evaporator bottoms product is transferred to the HLP. The overhead product from the CNP is sent to the PWD.	3	The design concept for the CNP evaporator has not been previously used in radioactive operations for the recovery of nitric acid, or proven by the Contractor by testing. This concept close couples the CNP with the CXP such that Cs eluate from the CXP IX column is received while nitric acid is recovered and sent back to the column for elution. Engineering calculations for the system design do not represent the variable feed compositions from the CXP and resultant variable product composition anticipated in the CNP. The CNP nitric acid product will likely require compositional adjustment to support subsequent reuse as an elution agent. The proposed continuous operation of the CNP will not efficiently accommodate this required chemical adjustment. This process design deficiency appears to be the result of the Pretreatment Reconfiguration studies that removed two CNP feed vessels and two CNP acid product vessel from the plant flowsheet. Laboratory-scale testing to demonstrate the integrated and simulated operations of the reboiler, separator vessel, condenser components, rectifier, and the demister pads has not been completed. The process control system has not been developed and tested. Analytical simulation of the CNP components has not included the full composition range of feed solutions to the evaporator (reboiler and separator vessel) from the CXP. Proposed operational changes to the CNP from the use of an alternative IX resin (e.g., use of RF resin) have not been factored into the CNP design and operational concept.
Cesium Ion Exchange Process System (CXP) The function of the CXP is to recover Cs-137 from the LAW received from UFP using ion exchange. The treated LAW is transferred to the TLP and the recovered Cs-137 is removed from the ion exchange columns using nitric acid.	5	Integrated testing of all CXP technology components has not been completed. Major items not tested include the nitrogen inerting collection piping and controls for removing hydrogen and other gases from the IX columns, and the ability to remove 99% by volume of the spherical RF resin from a prototypic IX column. Process testing has not been conducted, or planned to assess the following process operating conditions, assessment of physical degradation of irradiated resin samples and impact on resin performance from organics in the waste. BNI engineering studies indicate that precipitation of sodium oxalate and gibbsite solids will occur following filtration. The capability of the CXP to effectively treat feeds that contain freshly precipitated sodium oxalate and gibbsite solids, is not known. The CXP-VSL-00001 has no capability for blending solutions, suspending solids or chemical adjustments to reduce/mitigate the solids concentration in Cs IX feed or dissolve/remove solids.

Critical Technology Element and Description	Technology Readiness Level	Rationale
Treated LAW Evaporation Process System (TLP) The function of the TLP is to concentrate the treated LAW from the CXP. The LAW is concentrated by evaporation from about 5 molar Na to 8 to 10 molar Na. The overhead product from the TLP is sent to the RLD.	4	The vessels in the TLP (TLP-VSL-00009A/9B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the TLP, is determined to be immature (e.g., TRL 4) until mixing issues on the PJMs are resolved. The TLP design concept is adapted from a proven design (e.g., the 242-A Evaporator) operating at the Hanford Site and the extensive lab-scale and pilot-scale prototypic testing completed to demonstrate this technology. Technology issues evaluated and resolved included: design scale-up, effect of organics and recycle streams on process chemistry, testing and identification of an anti-foaming agent, evaluation of the plate out of aluminum and uranium salts on heat transfer surfaces, characterization of offgas effluents, and evaluation of the potential to form dimethyl mercury.
Waste Feed Evaporation Process System (FEP) The function of the FEP is to concentrate tank waste an process streams for feeding to the UFP. The nominal UFP feed will have a Na concentration of 5 molar and a solids content less than 4 wt%. The overhead product from the FEP is used for process flushes or sent to the RLD.	4	The vessels in the FEP (FEP-VSL-00017A/18B) may not meet minimum requirements for off-bottom suspension as determined by the Contractor. The designs of these vessels, and the FEP, are determined to be immature (e.g., TRL 4) until mixing issues on the PJMs are resolved. The FEP design concept is adapted from a proven design (i.e., the 242-A Evaporator) operating at the Hanford Site, and extensive lab-scale and pilot-scale prototypic testing has been completed to demonstrate this technology. Technology issues evaluated and resolved included: design scale-up, effect of organics and recycle streams on process chemistry, testing and identification of an anti-foaming agent, evaluation of the plate out of aluminum and uranium salts on heat transfer surfaces, characterization of offgas effluents, and evaluation of the potential to form dimethyl mercury.
Ultrafiltration Process System (UFP) The function of the UFP is to separate the HLW solids from the liquids, concentrate the solids, and wash and leach the solids to remove soluble chemical components. The UFP liquids are transferred to the CXP and the treated solids are transferred to the HLP.	3	Testing to define all requirements of the HLW sludge separation and treatment flowsheet has not been completed. Major flowsheet requirements and their status are: • The sludge treatment flowsheet, which is a combination of water washing, caustic leaching and oxidative leaching, has only been evaluated on paper. Plans for testing are in place. • The oxidative leaching process is limited to proof of principle tests and the final process has not been determined. Additional work required to define the concentrations of NaOH and $NaMnO_4$, the sequence of chemical addition, and the time and temperature of operation is planned or underway. • There is very little prototypical data on the filtration of treated sludge wastes (water, caustic and oxidative leached waste). • The ultrafiltration equipment technology concept has only been conceptualized on paper. There is not a representative testing platform available for technology evaluation. However, the Contractor is completing the design of a pilot-scale testing system for the testing and evaluation.

Critical Technology Element and Description	Technology Readiness Level	Rationale
Pulse Jet Mixer (PJM) system The functions of the PJMs are to mix tank waste liquids and solids to release hydrogen gas, support the mixing of waste with reagents, and blends liquids and solids to support process control and treatment of tank wastes.	4	Specific, quantifiable design requirements for the PJM technology have not been established to support design of the PJMs for the black cell vessels. The definition of the PJM mixing requirements must consider all functional requirements (i.e., safety, environmental, process control) of the vessels and the anticipated solution characteristics in the vessel.
Waste Feed Receipt Process System (FRP) The function of the FRP is to receive low solids containing wastes (less than 3.8 wt%) from the tank farm, store and blend the waste, and transfer the wastes to other process operations in PT.	4	Specific testing to support the adequacy of the mixing design for the FRP-VSL-00002A/2B/2C/2D has not been completed. A Computational Fluid Dynamic (CFD) assessment by the Contractor, and other mixing jet analyses completed, indicate that the current PJM operating specification may not be capable of adequately mixing the liquids and solids under normal conditions or achieve the off-bottom suspension criteria for hydrogen release.
HLW Lag Storage and Feed Blending Process System (HLP) The function of the HLP is to receive high solids containing wastes (up to 17 wt%) from the tank farm, store and blend the HLW slurries produced in the UFP waste, and transfer the wastes to other process operations in PT and the HLW facility.	4	Vessel HLP-VSL-00022 has been determined by the Contractor using CFD and other mixing jet analyses to not support basic mixing (e.g., off-bottom suspension) requirements. Vessels HLP-VSL-00027A, HLP-VSL-00027B and HLP-VSL -00028 were determined to be more mature because of the extensive testing completed by the Contractor to establish the technology requirements for mixing in the vessels. Specific mixing requirements for these vessels have not been clearly established. Other requirements of the HLP have not been demonstrated including the ability of these vessels to effectively mix washed and leached sludge solids. In addition, testing of the PJMs with clay simulants is still underway to assess PJM overblow and impacts of anti-foam on gas retention and release.

Critical Technology Element and Description	Technology Readiness Level	Rationale
Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD) The function of the PWD and RLD is to collect and manage process cycles, process line flushes, equipment flushes and sump drains fluids in the PT.	4	The RWD and RLD equipment technology lacks clear requirements for PJM performance. A mixing jet analyses completed by the Contractor determined that PWD-VSL-00044 will fail the off-bottom suspension criteria, and that PWD-VSL-00033 and PWD-VSL-00043 will only marginally meet the off-bottom suspension criteria for 50/50 mixing (condition that assumes that one half of the PJMs are operating at a time). Initial studies on the mixing of process streams have been completed. These studies indicate that careful control of the pretreatment process is critical for ensuring that solids that could lead to adverse process performance are not be created. Plans for the resolution of a number of potential issues are in place as part of the EFRT IRP M-6/P4, "Process Operating Limits Not Completely Defined."

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Appendix A – Determination of Critical Technology Elements

Appendix A– Determination of Critical Technology Elements

The working definition of the critical technology element (CTE) as defined in the *Technology Readiness Assessment (TRA) Deskbook* (2005) was used as a basis for identification of CTEs for the Waste Treatment and Immobilization Plant (WTP). The working definition is as follows:

> *A technology element is "critical" if the system being acquired depends on the technology element to meet operational requirements (with acceptable development, cost, and schedule and with acceptable production and operations costs) and if the technology element or its application is either new or novel.*
>
> *Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition, or its operational utility.*

The WTP Project is divided into five project elements:

- Analytical Laboratory (LAB)
- Balance of Facilities (BOF)
- Low-Activity Waste (LAW) Vitrification Facility
- High-Level Waste (HLW) Vitrification Facility
- Pretreatment (PT) Facility

Within each project element, the specific design features of the facility are divided into "systems." Thus, for convenience, the identification of the CTEs was done on a system basis. Most systems within the WTP facility are unique to the five project elements identified above. However, some selected systems are common to the treatment facilities (LAB, LAW, HLW, and PT). Where appropriate, these common systems were allocated to the five project elements identified above.

The process for identification of the CTEs for the PT Facility involved two steps:

1. The complete list of systems for PT Facility was initially screened by the Assessment Team (Appendix D) for potential CTEs. Systems directly involved in the processing of the tank waste, or handling of the primary products were identified as potential CTEs. The complete list of systems and those identified as potential CTEs are shown in Table A.1.

2. The final set of CTEs was determined by assessing the potential CTEs against the two sets of questions presented in Table A.2. A CTE is determined if there is a positive response to at least one of the questions in each of the question sets. This final assessment of the CTEs was completed jointly by the Assessment Team and the WTP Project Technology and Engineering staff.

   The specific responses to each of the questions for each potential CTE are provided in Table A.3.

The rationale for the selection of each of the systems as a CTE is summarized below.

CNP-Cesium Nitric Acid Recovery Process System (24590-WTP-3YD-CNP-00001)

The CNP is used to concentrate the acidic cesium (Cs) eluant from the elution of the Cs ion exchange (IX) columns and steam strip a portion of the nitric acid from the Cs eluant for recycle within the WTP flowsheet. The CNP uses a traditional evaporator design concept in which the pot boiler and vessel are separated. The evaporator vessel and demister tower are located in a black cell where no maintenance is required (except that the demister can be changed through an access plug in the top of the black cell) and the pot boiler is located in a hot cell where the tube bundle can be replaced. The CNP includes a fractionator tower for separating nitric acid from water. The acid fractionator is located in the black cell. The evaporation system is operated under vacuum to reduce the operating temperatures and corrosion rate of the materials. The evaporator system is being provided by a commercial vendor, Averna Technologies.

No schedule risks or cost risks were identified with the availability of the CNP. The end state requirements for the CNP products are known and are specified in the CNP system description (24590-WTP-3YD-CNP-00001). The technology is not new but has been modified and repackaged in that part of the system is designed as a permanent system (in the black cell) and part of the system is replaceable. The system design is unique and has not been demonstrated. Concerns were identified that there is no testing of this equipment concept in the application specified. The solubility limitations of the salts in the Cs eluate have not been completely evaluated. Some simulant testing was completed to investigate solubility relationships of major salts.

CXP-Cesium Ion Exchange System (24590-WTP-3YD-CXP-00001)

The CXP removes Cs from ultrafiltration system permeates. The CXP utilizes four IX columns. Three columns in series are in service while one is in standby mode. The Ultrafiltration Process System (UFP) permeate is transferred from the Cs IX feed vessel through heat exchangers into three IX columns that are operated in series. The first column is designated as the lead column. The second column is designated as the lag column. The third column is designated as the polishing column. The Cs treated LAW is collected in one of three vessels.

An initial design of the IX columns has been completed. The final design will be provided by a vendor yet to be selected. There is no cost risk and the end state requirements for the system are well-defined. Schedule risk results from the selection of a vendor for the final CXP IX column design. The vendor must be qualified to address issues (how to keep the resin bed level, breakthrough detection, flow rates, performance). There is also some schedule risk because the testing work on the IX resins candidates (resorcinol formaldehyde and SuperLig® 644), which could impact the final design, has not been completed. Most of the testing work for the resorcinol formaldehyde resin has been done using simulants based on Hanford tank waste supernatant compositions for tanks AP-101, AZ-102, AN-107, and AN-105, and not a wide range of wastes. Small column IX tests have been done on actual wastes from tanks AP-101 and AN-102.

The IX system is not new or novel, but it is modified. The candidate IX resins (resorcinol formaldehyde and SuperLig® 644) have not been manufactured commercially in large production batches or used in large-scale operations. Concerns were identified with the hydrogen gas removal system for the Cs IX columns, which has not been demonstrated. Additionally, concerns were identified with a device for measuring the level of resin in the IX columns, which has not been demonstrated. This device is crucial to verify removal of spent resin from the columns.

FEP-Waste Feed Evaporation Process (24590-WTP-3YD-FEP-00001)

The FEP is used to concentrate process recycles in the PT Facility and to prepare the ultrafiltration feed at a nominal concentration of 5 M sodium (Na). The FEP uses a vacuum evaporator design concept similar to the Hanford 242-A Evaporator. There are no schedule or cost risks, and end state requirements are known. The technology is not new, novel, or modified.

The evaporation technology is repackaged, because part of the system is in a black cell and part is in a hot cell. The evaporator vessel and demister tower are located in a black cell where no maintenance is required (except that the demister can be changed through an access plug in the top of the black cell) and the pot boiler is located in a hot cell where the tube bundle can be replaced. The system is not expected to perform beyond the demonstrated capability. The evaporator includes more bubble trays than is typically used, but the decontamination factor is not greater than supported by vendor data. Currently, there are unresolved issues with chemical and physical plugging of some of the process pipe lines. The waste feeds have not been completely characterized or evaluated, and there may be chemistry issues with the solubility's of the leachate streams. The evaporator system is being provided by a commercial vendor, Averna Technologies.

FRP-Waste Feed Receipt Process (24590-WTP-3YD-FRP-00001)

The FRP process consists of 4 large vessels (~380,000 gallons), each having 12 pulse jet mixers (PJM). The FRP is used to receive low solids concentration slurries (> 5 wt%) from the Hanford Site tank farms and store process recycles within the PT Facility. The vessels have already been installed in the WTP. There are no known schedule or cost risks. However, based on recent PJM mixing analyses additional limitations may need to be placed on the received waste feeds. The PJMs may not impart enough power to the fluid to suspend solids.

The technology is not new or novel. However, the size of the PJMs is unprecedented in fluidic mixing technology. The PJMs may be expected to perform beyond currently demonstrated capability.

HLP-HLW Lag Storage and Feed Blending (24590-WTP-3YD-HLP-00001)

The HLP vessels are used to store and blend high solids concentration feed slurries and will nominally contain non-Newtonian fluids. There are current concerns with the adequacy of the PJM wear plate thicknesses on vessels HLP-VSL-00027A, HLP-VSL-00027B, and HLP-VSL-00028, and the PJM design for vessel HLW-VSL-00022. In addition, HLP-VSL-00022 may need to be re-designed to support the mixing on non-Newtonian slurries.

The HLP vessels are in the vendor shops being built. There are potential schedule and cost risks because of unresolved design issues with these vessels. The technology is not new, but it has been modified and/ or repackaged. The technology was demonstrated for non-Newtonian fluids in PJM testing conducted by the WTP Contractor, but the PJMs must also suspend solids from Newtonian fluids. HLP-VSL-00022 should have been designed to handle higher solids content and may require spargers to assist in mixing.

PJM-Pulse Jet Mixers (24590-WTP-3YD-50-00003)

PJMs are used within the WTP to dissipate gases, blend liquids, and suspend solids for sampling and transport. This system is similar to the system used at the Sellafield site, United Kingdom, for non-Newtonian fluids. For Newtonian fluids, there may not be enough power imparted from the PJM to the bulk fluid to suspend the solids and keep them from settling on the bottom. There are schedule and cost risks, because of unresolved design issues with the PJMs for the Newtonian vessels. These concerns will

be resolved as part of an ongoing testing program. End state requirements for PJMs are documented but performance has yet to be validated.

The PJM mixing technology is not new, but it has been modified and repackaged. The PJM discharge velocity for all WTP applications has yet to be determined based upon experimental data. The required operational modifications may require the PJMs to perform beyond their demonstrated capability. Solids concentrations are an order of magnitude higher at the WTP than at the Sellafield application, and the PJM capability for Newtonian off bottom suspension has not been demonstrated. The Sellafield site used PJMs to mix acidic waste streams feed, the WTP uses an alkaline feed. The acidic and alkaline waste streams have significantly different rheological properties and extension of the PJM data from Sellafield may not be possible.

PJV-Pulse Jet Ventilation System (24590-WTP-3YD-PJV-00001)

The PJV is the exhaust system for the vent air for the PJMs. There are no schedule or cost risks. The demisters, high-efficiency particulate air (HEPA) filters, and fans are well-proven in any application. End state requirements are known, but contamination creep into the system was identified as an issue. However, testing has shown that the efficacy of the flush system for contamination removal. The technology is not new or novel.

The PJV is modified because it used a HEPA filter configuration that is different than previously used in the U.S. As a result, the vendor has been required to provide additional testing and analysis to prove the HEPA filters can be U.S.-code compliant. The U.S. HEPA code requires the filter to be inline with the direct flow. The British designed system allows air flow radially from the filters. The vendor has had difficulty getting the filter qualified to the U.S. code. The system is repackaged because it uses the British system with a different seal (blue gel with a knife edge) compared to standard HEPA filters, but similar seals have been extensively used at the Hanford Site.

PVP- Pretreatment Vessel Vent Process System (24590-WTP-3YD-PVP-00001)

The PVP is an offgas treatment system for the PJM and RFD air supply. This system uses standard equipment except for the radial HEPA filters. There are no schedule or cost risks, but it may not meet end state requirements if contamination creep occurs in the PVP. A Savannah River National Laboratory (SRNL) report on PJM creep documents the efficacy of the flush system for contamination removal. The technology is not new or novel, but it is modified. The U.S. HEPA code requires the filter to be inline with the direct flow. The British designed system allows air flow radially from the filters. The vendor has had difficulty getting the filter qualified to the U.S. code. The system is repackaged because it uses the British system with a different seal (blue gel with a knife edge) compared to standard HEPA filters, but similar seals have been used extensively at the Hanford Site.

PWD-Plant Wash Drain (24590-WTP-3YD-PWD-00001)

The PWD is used to receive recycle streams from the HLW Facility and other pretreatment process streams. The PWD includes leak detection, drains, and overflow systems. Vessels PWD-VSL-00033, -00043, -00045, and -00046 are installed. PWD-VSL-00044 is in fabrication, and PJM modifications are being incorporated. PWD-VSL-00015 and -00016 have been delivered. There are no uncertainties with end state, but there are potential cost and schedule risks if PJM testing shows that PWD-VSL-00033 and -00043 must be modified to include wear plates, or the PJMs in PWD-VSL-00033, -00043, and -00044 require further upgrades to increase drive velocities.

The PJM mixing technology is not new, but it has been modified and repackaged. The PJM discharge velocity for all WTP applications has yet to be determined based upon experimental data. The required operational modifications may require the PJMs to perform beyond their demonstrated capability. Solids concentrations are an order of magnitude higher at the WTP than at the Sellafield application, and the PJM capability for Newtonian off-bottom suspension has not been demonstrated. The Sellafield site used PJMs to mix acidic waste streams feed, the WTP uses an alkaline feed. The acidic and alkaline waste streams have significantly different rheological properties and use of the PJM data from Sellafield may not be possible.

TCP-Treated LAW Concentrate Storage Process (24590-WTP-3YD-TCP-00001)

The TCP consists of one vessel (TCP-VSL-00001) that is a hold point before its contents are transferred to the LAW Vitrification Facility. PJMs are used for mixing, which have yet to be experimentally verified. Issues were identified on the potential for precipitation in the transfer pipelines and methods to remove phosphate plugging are being evaluated. There are no cost risks, schedule risks, but there are some end state questions on the chemistry of vessel contents. The technology is not new, modified, or repackaged. It will not be required to perform beyond the demonstrated capability.

TLP-Treated LAW Evaporation Process (24590-WTP-3YD-TLP-00001)

The TLP is used to concentrate the decontaminated LAW waste stream to support LAW melter operations. The TLP requires the use of vacuum evaporators similar to the Hanford 242-A Evaporator. The LAW melter feed is evaporated to 8 to 10 M Na. There are no cost risks, schedule risks, but there are some end state issues on potential chemistries that might cause chemical and physical plugging that are not resolved. The system is not new, novel, or modified. The system is repackaged, because part of the system is in a black cell and part is in a hot cell. The system is not expected to perform beyond demonstrated capability. There are more bubble trays than is typically used, but the decontamination factor is not greater than what vendor data supports. The evaporator system is being provided by a commercial vendor, Averna Technologies.

UFP-Ultrafiltration Process (24590-WTP-3YD-UFP-00001)

The UFP is used to separate the tank waste solids and liquids, support washing of tank waste solids to reduce their mass, and is a major treatment system in the PT Facility.

In late 2004, DOE identified, as part of their oversight of the WTP PT Facility design, that the UFP was undersized to meet DOE's requirements and the process chemistry used to treat the tank waste solids was incorrect. Subsequently, DOE directed the WTP Contractor to complete a series of engineering studies to correct the process flowsheet and identify changes to increase the design capacity of the UFP. An expert panel review completed in early 2006 also identified the same issues with the UFP. Since the time of the expert panel review, the DOE has further directed the WTP Contractor to:

- Complete extensive testing of the ultrafiltration process using laboratory-scale testing, including testing with actual Hanford Site tank wastes, and
- Complete testing of a pilot-scale ultrafiltration system to validate the proposed plant-scale ultrafiltration system design and obtain data to project plant-scale performance.

There are significant cost risks and schedule risks associated with the technology and uncertainties in the end state requirements. The technology is not new or novel, but it is extensively modified. The technology is not expected to perform outside the demonstrated capability in industrial applications, but it is not known whether the technology will meet the end state requirements. A significant testing program is in place to resolve chemistry and design issues.

The following systems were not selected as CTEs. The rationale for the selection of each of the systems as non-CTEs is summarized below.

CRP-Cesium Resin Addition Process (24590-WTP-3YD-CRP-00001)

This process is to wash resin before it is placed in the WTP IX columns using mixing, filtration, and gravity flow. The resin is then slurried into the columns. The technology is not novel, modified, or repackaged. The environment is similar to other standard industry applications.

PIH-Pretreatment In-Cell Handling System (24590-WTP-3YD-PIH-00001)

PIH includes the in-cell equipment for maintenance including manipulators, cranes, shears, saws, and decontamination tanks. The main crane includes a power manipulator and three hoists (one 30-ton and two 2-ton hoists) that rotate equipment to the position needed by the power manipulator. An expert panel review recently commented that crane utilization should be reduced for cranes that needed to be remotely maintained. The PIH was re-designed to add a second pretreatment bridge crane. There are no schedule risks or costs risks. The operational assessments validated that end state requirements, in terms of crane utilization, can be met with this system. The technology is not novel, modified, or repackaged. The environment is not different than previous applications.

RDP-Spent Resin Collection/Dewatering Process (24590-WTP-3YD-RDP-00001)

The RDP consists of three vessels (RDP-VSL-00062A/-00062B/-00062C) where spent IX resin is discharged from the CXP. The spent resin is sampled and slurries to a commercial cask/disposal liner system for dewatering. Following dewatering and drying, the resin is removed from the PT Facility for disposal.

The RDP/resin disposal system uses standard equipment. The RDP vessels are mixed with PJMs. The RDP vessels are in fabrication. The RDP/resin disposal system is not novel, modified, or repackaged, and it will not be expected to perform beyond the original design attention. Some poly-styrene resins get soft and mushy when irradiated. The resins can become sticky and result in plugging. The point where oxygen loss and irradiation causes this to happen is not understood, but it will be resolved as part of testing.

RLD-Radioactive Liquid Waste (24590-WTP-3YD-RLD-00001)

The RLD handles liquid waste for interim storage before being transferred to the effluent system. The RLD consists of four vessels. RLD-VSL-00017A/-00017B receive caustic scrubber solution from the LAW Vitrification Facility offgas system, and vessels RLD-VSL-00006A/-00006B receive overhead from the FEP and TLP and evaporators. Solutions from vessel RLD-VSL-00006B are transferred to Hanford's Liquid Effluent Retention Facility (LERF). These vessels have no PJMs. Vessels RLD-VSL-00017A/ -00017B are in a low radiation areas and vessels RLD-VSL-00006A/-00006B are located outside of the PT Facility. There is no schedule risk, cost risk, or uncertainty in the end state requirements. The system is not new, modified, or repackaged. The technology will not be used beyond its demonstrated capacity.

RWH-Radioactive Solid Waste (24590-WTP-3YD-RWH-00001)

The RWH includes the equipment and containers used to package solid wastes. Spent resins, spent filters, and end cell waste are placed into standard low-level waste disposal containers. Overhead cranes, manipulators, and boggies move baskets of failed and size reduced equipment and filters into the drums

and put the lid on the drums. A boggie carries the drum to the truck bay. End cell waste is swabbed prior to acceptance, and it is similarly placed into a cask. There is a carbon dioxide (CO_2) decontamination capability for the disposal cask if required. There are no schedule risks, cost risks, or uncertainty in the end state requirements. The system is not new, modified, or repackaged. Some unique tools may be required for cutting large equipment items like the ultrafilters assembly, but it will not use technology beyond its demonstrated capability. Standard decontamination techniques will be used. More detailed design development of the RWH is in progress.

Table A.1. Identification of Critical Technology Elements (Systems) in the Pretreatment Facility

System Locators	System Title	Document number	Include in Initial CTE Evaluation?
ARV,C1V,C2V, C3V,C5V	Atmospheric Reference Ventilation; Cascade Ventilation System	24590-PTF-3YD-60-00001	No
BNG	Bottled Nitrogen Gas	24590-PTF-3YD-MXG-00001	No
BSA	Breathing Service Air	24590-PTF-3YD-BSA-00002	No
BSA	Breathing Service Air	24590-PTF-3YD-BSA-00001	No
C1V	Cascade Ventilation System	24590-PTF-3YD-C1V-00001	No
C2V	Cascade Ventilation System	24590-PTF-3YD-C2V-00001	No
C3V	Cascade Ventilation System	24590-PTF-3YD-C3V-00001	No
C5V	Cascade Ventilation System	24590-PTF-3YD-C5V-00001	No
CHW	Chilled Water	24590-PTF-3YD-CHW-00001	No
CNP	Cesium Nitric Acid Recovery Process	24590-PTF-3YD-CNP-00001	Yes
CRP	Cesium Resin Addition Process	24590-PTF-3YD-CRP-00001	Yes
CXP	Cesium Ion Exchange Process	24590-PTF-3YD-CXP-00001	Yes
DOW	Domestic Water System	24590-PTF-3YD-DOW-00001	No
FEP	Waste Feed Evaporation Process	24590-PTF-3YD-FEP-00001	Yes
FRP	Waste Feed Receipt Process	24590-PTF-3YD-FRP-00001	Yes
HLP	HLW Lag Storage and Feed Blending Process	24590-PTF-3YD-HLP-00001	Yes
HPS,LPS,SCW	High Pressure Steam	24590-PTF-3YD-HPS-00001	No
ISA	Instrument Service Air	24590-PTF-3YD-ISA-00001	No
PFH	Pretreatment Filter Cave Handling System	24590-PTF-3YD-PFH-00001	No
PIH	Pretreatment In Cell Handling System	24590-PTF-3YD-PIH-00001	Yes
PJV	Pulse Jet Ventilation System	24590-PTF-3YD-PJV-00001	Yes
PSA	Plant Service Air	24590-PTF-3YD-PSA-00001	No
PSA ITS	Plant Service Air/Important to Safety	24590-PTF-3YD-PSA-00002	No
PTJ	Mechanical Handling CCTV	24590-PTF-3YD-PTJ-00001	No
PVP	Pretreatment Vessel Vent Process System	24590-PTF-3YD-PVP-00001	Yes
PVV	Pretreatment Vessel Vent Exhaust System	24590-PTF-3YD-PVV-00001	No
PWD	Plant Wash and Disposal Leak Detection	24590-PTF-3YD-PWD-00002	Yes
PWD	Plant Wash and Disposal/Radioactive Liquid Disposal	24590-PTF-3YD-PWD-00001	Yes
RDP	Spent Resin Collection and Dewatering Process	24590-PTF-3YD-RDP-00001	Yes
RWH	Radioactive Solid Waste	24590-WTP-3YD-RWH-00001	Yes
RLD	Radioactive Liquid Waste	24590-PTF-3YD-RLD-00001	Yes
TCP	Treated LAW Concentrate Storage Process	24590-PTF-3YD-TCP-00001	Yes
TLP	Treated LAW Evaporation Process	24590-PTF-3YD-TLP-00001	Yes
UFP	Ultrafiltration Process	24590-PTF-3YD-UFP-00001	Yes
	Pretreatment Facility Flowsheet	NA	Yes

Table A.2. Questions used to determine the Critical Technology Element for the Pretreatment Facility Technology Readiness Level Assessment

First Set	1. Does the technology directly impact a functional requirement of the process or facility? 2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required? 3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns? 4. Are there uncertainties in the definition of the end state requirements for this technology?
Second Set	1. Is the technology (system) new or novel? 2. Is the technology (system) modified? 3. Has the technology been repackaged so that a new relevant environment is realized? 4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

Table A.3. Summary of Question Responses for the Pretreatment Facility Systems that were determined to be Critical Technology Elements

System	Cesium Nitric Acid Recovery Process System, CNP	Cesium Resin Addition Process System, CRP	Cesium Ion Exchange Process System, CXP	Waste Feed Evaporation Process System, FEP	Waste Feed Receipt Process System, FRP	HLW Lag Storage and Feed Blending Process System, HLP	Pretreatment In -Cell Handling System, PIH	Pulse Jet Mixer System, PJM	Pulse Jet Ventilation System, PJV
Critical Technology Element	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
First Question Set	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1. Does the technology directly impact a functional requirement of the process or facility?	Y	Y	Y	Y	Y	Y	Y	Y	Y
2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required?	N	N	N	N	N	Y	N	Y	N
3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	N	N	N	N	N	Y	N	Y	N
4. Are there uncertainties in the definition of the end state requirements for this technology?	N	N	N	N	Y	Y	N	N	N
Second Question Set	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes
1. Is the technology (system) new or novel?	N	N	N	N	N	N	N	N	N
2. Is the technology (system) modified?	N	N	Y	N	Y	Y	N	Y	Y
3. Has the technology been repackaged so that a new relevant environment is realized?	Y	N	Y	Y	Y	Y	N	Y	Y
4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?	N	N	N	N	Y	Y	N	Y	N

Table A.3. Summary of Question Responses for the Pretreatment Facility Systems that were determined to be Critical Technology Elements (cont.)

System	Pretreatment Vessel Vent Process System, PVP	Plant Wash and Disposal System, PWD	Spent Resin and Collection Dewatering Process System, RDP	Radioactive Liquid Waste Disposal System, RLD	Radioactive Solid Waste System, RWH	Treated LAW Concentrate Storage process, TCP	Treated LAW Evaporation Process, TLP	Ultrafiltration Process System, UFP
Critical Technology Element	Yes	Yes	No	No	No	No	Yes	Yes
First Question Set	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1. Does the technology directly impact a functional requirement of the process or facility?	Y	Y	Y	Y	Y	Y	Y	Y
2. Do limitations in the understanding of the technology result in a potential schedule risk; i.e., the technology may not be ready for insertion when required?	N	Y	N	N	N	N	N	Y
3. Do limitations in the understanding of the technology result in a potential cost risk; i.e., the technology may cause significant cost overruns?	N	Y	N	N	N	N	N	N
4. Are there uncertainties in the definition of the end state requirements for this technology?	N	N	N	N	Y	Y	N	N
Second Question Set	Yes	Yes	No	No	No	No	Yes	Yes
1. Is the technology (system) new or novel?	N	N	N	N	N	N	N	N
2. Is the technology (system) modified?	Y	Y	N	N	N	N	N	Y
3. Has the technology been repackaged so that a new relevant environment is realized?	Y	Y	N	N	N	N	Y	Y
4. Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?	N	Y	N	N	N	N	N	Y

A.1 References

1. 24590-PTF-3YD-CNP-00001, Rev. 0, *System Description for Cesium Nitric Acid Recovery Process-System CNP*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

2. 24590-PTF-3YD-CRP-00001, Rev. 0, *System Description for Cesium Resin Addition Process System CRP*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

3. 24590-PTF-3YD-CXP-00001, Rev. 0, *System Description for Cesium Ion Exchange Process System CXP*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

4. 24590-PTF-3YD-FEP-00001, Rev. 0, *System Description for Waste Feed Evaporation Process (FEP)*, September 10, 2002, Bechtel National, Inc., Richland, Washington.

5. 24590-PTF-3YD-FRP-00001, Rev. 0, *System Description for Waste Feed Receipt Process (FRP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

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7. 24590-PTF-3YD-PIH-00001, Rev. 0, *System Description for Pretreatment In-Cell Handling System*, November 3, 2003, Bechtel National, Inc., Richland, Washington.

8. 24590-PTF-3YD-PJV-00001, Rev. 0, *System Description for PTF Pulse Jet Ventilation System*, September 5, 2003, Bechtel National, Inc., Richland, Washington.

9. 24590-PTF-3YD-PVP-00001, Rev. 0, *System Description for Pretreatment Vessel Vent Process System*, September 10, 2002, Bechtel National, Inc., Richland, Washington.

10. 24590-PTF-3YD-PWD-00001, Rev. 1, *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD*, September 22, 2003, Bechtel National, Inc., Richland, Washington.

11. 24590-PTF-3YD-RDP-00001, Rev. 0, *System Description for Spent Resin Collection and Dewatering Process-System RDP*, September 11, 2003, Bechtel National, Inc., Richland, Washington.

12. 24590-PTF-3YD-RWH-00001, Rev. 0, *System Description for WTP System RHW Radioactive Solid Waste Handling*, July 12, 2005, Bechtel National, Inc., Richland, Washington.

13. 24590-PTF-3YD-TCP-00001, Rev. 1, *System Description for Treated LAW Concentrate Storage process System (TCP)*, March 9, 2006, Bechtel National, Inc., Richland, Washington.

14. 24590-PTF-3YD-TLP-00001, Rev. 0, *System Description for Treated LAW Evaporation Process (TLP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

15. 24590-PTF-3YD-UFP-00001, Rev. 0, *System Description for Ultrafiltration Process System(UFP)*, September 11, 2002, Bechtel National, Inc., Richland, Washington.

16. 24590-WTP-3YD-50-00003, Rev. A, *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems*, May 19, 2004, Bechtel National, Inc., Richland, Washington.

17. DOD 2005, *Department of Defense, Technology Readiness Assessment (TRA) Deskbook*, May 2005, Prepared by the Deputy Undersecretary of Defense for Science and Technology (DUSD(S&T)).

Appendix B – Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix B – Technology Readiness Level Calculator as Modified for DOE Office of Environmental Management

Appendix B presents the questions used for assessing the technology maturity of U.S. Department of Energy (DOE) Office of Environmental Management (EM) waste processing and treatment technologies using a modified version of the Air Force Research Laboratory Technology Readiness Level (TRL) Calculator. The following TRL questions were developed for the evaluation of the WTP Pretreatment (PT) Facility systems in their respective tables as identified below.

- Table B.1 for TRL 1
- Table B.2 for TRL 2
- Table B.3 for TRL 3
- Table B.4 for TRL 4
- Table B.5 for TRL 5
- Table B.6 for TRL 6

The TRL Calculator was used to assess the TRL of the WTP critical technology elements (CTE). The assessment begins by using the top-level questions listed in Figure B.1 to determine the anticipated TRL that will result from the detailed questions. The anticipated TRL was determined from the question with the first "yes" answer from the list in Figure B.1. Evaluation of the detailed questions was started one level below the anticipated TRL. If it was determined from the detailed questions that the technology had not attained the maturity of the starting level, the next levels down were evaluated in turn until the maturity level could be determined.

The Calculator provides a standardized, repeatable process for evaluating the maturity of the hardware or software technology under development. The first columns in Tables B.1 to B.6 identify whether the question applies to Hardware (H), Software (S), or both. The second columns in Tables B.1 to B.6 identify the areas of readiness being evaluated: technical (T), programmatic (P), and manufacturing/ quality requirements (M). A technology is determined to have reached a given TRL if column 3 is judged to be 100% complete for all questions.

If Yes, Then Logic		Top Level Question
TRL 9	→	Has the actual equipment/process successfully operated in the full operational environment (hot operations)?
TRL 8	→	Has the actual equipment/process successfully operated in a limited operational environment (hot commissioning)?
TRL 7	→	Has the actual equipment/process successfully operated in the relevant operational environment (cold commissioning)?
TRL 6	→	Has prototypical engineering-scale equipment/process testing been demonstrated in a relevant environment?
TRL 5	→	Has bench-scale equipment/process testing been demonstrated in a relevant environment?
TRL 4	→	Has laboratory-scale testing of similar equipment systems been completed in a simulated environment?
TRL 3	→	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?
TRL 2	→	Has an equipment and process concept been formulated?
TRL 1	→	Have the basic process technology process principles been observed and reported?

Figure B.1. Top Level Questions Establish Expected Technology Readiness Level

Table B.1. Technology Readiness Level 1 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		"Back of envelope" environment
B	T		Physical laws and assumptions used in new technologies defined
S	T		Have some concept in mind for software that may be realizable in software
S	T		Know what software needs to do in general terms
B	T		Paper studies confirm basic principles
S	T		Mathematical formulations of concepts that might be realizable in software
S	T		Have an idea that captures the basic principles of a possible algorithm
B	P		Initial scientific observations reported in journals/conference proceedings/technical reports
B	T		Basic scientific principles observed
B	P		Know who cares about the technology; e.g., sponsor, money source
B	T		Research hypothesis formulated
B	P		Know who will perform research and where it will be done
H-Hardware element, contains no appreciable amount of software B-Some Hardware and Software M-Manufacturing and quality			S-Completely a Software system T-Technology, technical aspects P-Programmatic, customer focus, documentation

Table B.2. Technology Readiness Level 2 Questions

H/S/ Both	Cat	% Complete	Criteria
B	P		Customer identified
B	T		Potential system or components have been identified
B	T		Paper studies show that application is feasible
B	P		Know what program the technology will support
B	T		An apparent theoretical or empirical design solution identified
H	T		Basic elements of technology have been identified
B	T		Desktop environment
H	T		Components of technology have been partially characterized
H	T		Performance predictions made for each element
B	P		Customer expresses interest in the application
S	T		Some coding to confirm basic principles
B	T		Initial analysis shows what major functions need to be done
H	T		Modeling and Simulation only used to verify physical principles
B	P		System architecture defined in terms of major functions to be performed
S	T		Experiments performed with synthetic data
B	P		Requirements tracking system defined to manage requirements creep
B	T		Rigorous analytical studies confirm basic principles
B	P		Analytical studies reported in scientific journals/conference proceedings/technical reports.
B	T		Individual parts of the technology work (No real attempt at integration)
S	T		Know what hardware software will be hosted on
B	T		Know what output devices are available
B	P		Preliminary strategy to obtain TRL 6 developed (e.g., scope, schedule, cost)
B	P		Know capabilities and limitations of researchers and research facilities
B	T		Know what experiments are required (research approach)
B	P		Qualitative idea of risk areas (cost, schedule, performance)

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
M-Manufacturing and quality
S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table B.3. Technology Readiness Level 3 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Academic environment
H	T		Predictions of elements of technology capability validated by analytical studies
B	P		The basic science has been validated at the laboratory-scale
H	T		Science known to extent that mathematical and/or computer models and simulations are possible
B	P		Preliminary system performance characteristics and measures have been identified and estimated
S	T		Outline of software algorithms available
H	T		Predictions of elements of technology capability validated by Modeling and Simulation (M&S)
S	T		Preliminary coding verifies that software can satisfy an operational need
H	M		No system components, just basic laboratory research equipment to verify physical principles
B	T		Laboratory experiments verify feasibility of application
H	T		Predictions of elements of technology capability validated by laboratory experiments
B	P		Customer representative identified to work with development team
B	P		Customer participates in requirements generation
B	T		Cross technology effects (if any) have begun to be identified
H	M		Design techniques have been identified/developed
B	T		Paper studies indicate that system components ought to work together
B	P		Customer identifies transition window(s) of opportunity
B	T		Performance metrics for the system are established
B	P		Scaling studies have been started
S	T		Experiments carried out with small representative data sets
S	T		Algorithms run on surrogate processor in a laboratory environment
H	M		Current manufacturability concepts assessed
S	T		Know what software is presently available that does similar task (100% = Inventory completed)
S	T		Existing software examined for possible reuse
H	M		Sources of key components for laboratory testing identified
S	T		Know limitations of presently available software (analysis of current software completed)
B	T		Scientific feasibility fully demonstrated
B	T		Analysis of present state of the art shows that technology fills a need
B	P		Risk areas identified in general terms
B	P		Risk mitigation strategies identified
B	P		Rudimentary best value analysis performed for operations
B	P		The individual system components have been tested at the laboratory-scale

H-Hardware element, contains no appreciable amount of software
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S-Completely a Software system
T-Technology, technical aspects
P-Programmatic, customer focus, documentation

Table B.4. Technology Readiness Level 4 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Cross technology issues (if any) have been fully identified
H	M		Laboratory components tested are surrogates for system components
H	T		Individual components tested in laboratory/by supplier (contractor's component acceptance testing)
B	T		Subsystems composed of multiple components tested at lab-scale using simulants
H	T		Modeling and simulation used to simulate some components and interfaces between components
S	T		Formal system architecture development begins
B	P		Overall system requirements for end user's application are documented
B	P		System performance metrics measuring requirements have been established
S	T		Analysis provides detailed knowledge of specific functions software needs to perform
B	P		Laboratory testing requirements derived from system requirements are established
H	M		Available components assembled into laboratory-scale system
H	T		Laboratory experiments with available components show that they work together (lab kludge)
S	T		Requirements for each system function established
S	T		Algorithms converted to pseudocode
S	T		Analysis of data requirements and formats completed
S	T		Stand-alone modules follow preliminary system architecture plan
H	T		Analysis completed to establish component compatibility
S	M		Designs verified through formal inspection process
B	P		Science and Technology exit criteria established
B	T		Technology demonstrates basic functionality in simulated environment
S	P		Able to estimate software program size in lines of code and/or function points
H	M		Scalable technology prototypes have been produced
B	P		Draft conceptual designs have been documented
H	M		Equipment-scaleup relationships are understood/accounted for in technology development program
B	T		Controlled laboratory environment used in testing
B	P		Initial cost drivers identified
S	T		Experiments with full-scale problems and representative data sets
B	M		Integration studies have been started
B	P		Formal risk management program initiated
S	T		Individual functions or modules demonstrated in a laboratory environment
H	M		Key manufacturing processes for equipment systems identified
B	P		Scaling documents and designs of technology have been completed
S	T		Some ad hoc integration of functions or modules demonstrates that they will work together
H	M		Key manufacturing processes assessed in laboratory
B	P		Functional work breakdown structure developed (functions established)
B	T		Low fidelity technology "system" integration and engineering completed in a lab environment
H	M		Mitigation strategies identified to address manufacturability/producibility shortfalls
B	P		Technology availability dates established

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S-Completely a Software system
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Table B.5. Technology Readiness Level 5 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Cross technology effects (if any) have been fully identified (e.g., system internally consistent)
B	T		Plant size components available for testing
B	T		System interface requirements known (how will system be integrated into the plant?)
B	P		System requirements flow down through work breakdown structure (design engineering begins)
S	T		System software architecture established
B	T		Requirements for technology verification established
S	T		External process/equipment interfaces described as to source, structure, and requirements
S	T		Analysis of internal system interface requirements completed
B	T		Lab-scale similar system tested with limited range of actual wastes, if applicable
B	T		Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)
H	M		Significant engineering and design changes
S	T		Coding of individual functions/modules completed
H	M		Prototypes of equipment system components have been created (know how to make equipment)
H	M		Tooling and machines demonstrated in lab for new manufacturing processes to make component
B	T		High-fidelity lab integration of system completed, ready for test in relevant environments
H	M		Manufacturing techniques have been defined to the point where largest problems defined
H	T		Lab-scale similar system tested with range of simulants
H	T		Fidelity of system mock-up improves from laboratory to bench-scale testing
B	M		Reliability, Availability, Maintainability Index (RAMI) target levels identified
H	M		Some special purpose components combined with available laboratory components for testing
H	P		Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared
B	T		Laboratory environment for testing modified to approximate operational environment
B	T		Component integration issues and requirements identified
H	P		Detailed design drawings have been completed to support specification of pilot testing system
B	T		Requirements definition with performance thresholds and objectives established for final plant design
S	T		Algorithms run on processor with characteristics representative of target environment
B	P		Preliminary technology feasibility engineering report completed
B	T		Integration of modules/functions demonstrated in a laboratory/bench-scale environment
H	T		Formal control of all components to be used in final system
B	P		Configuration management plan in place
B	P		Risk management plan documented
S	T		Functions integrated into modules
S	T		Formal inspection of all modules to be used in the final design
S	T		Individual functions tested to verify that they work
S	T		Individual modules and functions tested for bugs
S	T		Integration of modules/functions demonstrated in a laboratory environment
S	P		Formal inspection of all modules/components completed as part of configuration management
H	P		Individual process and equipment functions tested to verify that they work (e.g., test reports)

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Table B.6. Technology Readiness Level 6 Questions

H/S/ Both	Cat	% Complete	Criteria
B	T		Performance and behavior of subcomponent interactions understood (including tradeoffs)
H	M		Reliability, Availability, Maintainability Index (RAMI) levels established
B	M		Frequent design changes occur
H	P		Draft design drawings for final plant system are nearly complete
B	T		Operating environment for final system known
B	P		Collection of actual maintainability, reliability, and supportability data has been started
B	P		Estimated cost of the system design is identified
B	T		Engineering-scale similar system tested with a range of simulants
B	P		Plan for demonstration of prototypical equipment and process testing completed, results verify design
B	T		Modeling and simulation used to simulate system performance in an operational environment
H	T		Operating limits for components determined (from design, safety, and environmental compliance)
B	P		Operational requirements document available
B	P		Off-normal operating responses determined for engineering-scale system
B	T		System technical interfaces defined
B	T		Component integration demonstrated at an engineering-scale
B	P		Scaling issues that remain are identified and supporting analysis is complete
B	P		Analysis of project timing ensures technology will be available when required
S	T		Analysis of database structures and interfaces completed
B	P		Have begun to establish an interface control process
B	P		Acquisition program milestones established for start of final design (CD-2)
H	M		Critical manufacturing processes prototyped
H	M		Most pre-production hardware is available to support fabrication of the system
B	T		Engineering feasibility fully demonstrated (e.g., will it work?)
S	T		Prototype implementation includes functionality to handle large-scale realistic problems
S	T		Algorithms partially integrated with existing hardware / software systems
H	M		Materials, process, design, and integration methods have been employed (e.g., can design be produced?)
S	T		Individual modules tested to verify that the module components (functions) work together
B	P		Technology ”system” design specification complete and ready for detailed design
H	M		Components are functionally compatible with operational system
H	T		Engineering-scale system is high-fidelity functional prototype of operational system
S	T		Representative software system or prototype demonstrated in a laboratory environment
B	P		Formal configuration management program defined to control change process
B	M		Integration demonstrations have been completed (e.g., construction of testing system)
B	P		Final Technical Report on Technology completed
B	T		Waste processing issues have been identified and major ones have been resolved
S	T		Limited software documentation available
S	P		Verification, Validation, and Accreditation (VV&A) initiated
H	M		Process and tooling are mature to support fabrication of components/system
H	M		Production demonstrations are complete (at least one time)
S	T		"Alpha" version software has been released
S	T		Representative model tested in high-fidelity lab/simulated operational environment

H-Hardware element, contains no appreciable amount of software
B-Some Hardware and Software
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Appendix C – Technology Readiness Level Summary for WTP Critical Technology Elements for PT Facility

Appendix C – Technology Readiness Level Summary for WTP Critical Technology Elements for PT Facility

Appendix C summarizes the responses to the specific criteria identified in the Technology Readiness Level (TRL) Calculator (Appendix B) for all systems identified as critical technology elements (CTE). The TRL criteria at the highest level scored or level six are presented. This approach provides a documented record to explain why the next highest level was not achieved. Only the FEP and TLP achieved a TRL 6. The responses to questions that reflected the criterion that was not completed are shown in **bold** in the tables below. The responses to the following TRLs are included in the following tables. .

- Table C.1 – Cesium Nitric Acid Recovery Process System (CNP), (TRL 4)
- Table C.2 – Cesium Ion Exchange Process System (CXP), (TRL 6)
- Table C.3 – Waste Feed Evaporation Process System (FEP), (TRL 6)
- Table C.4 – Treated LAW Evaporation Process System (TLP), (TRL 6)
- Table C.5 – Ultrafiltration Process System (UFP), (TRL 4)
- Table C.6 – Pulse Jet Mixers (PJM), (TRL 5)
- Table C.7 – Waste Feed Receipt Process System (FRP), (TRL 5)
- Table C.8 – HLW Lag Storage and Feed Blending Process System (HLP), (TRL 5)
- Table C.9 - Plant Wash and Disposal System (PWD)/ Radioactive Liquid Waste Disposal System (RLD), (TRL 5)

Table C.1. Technology Readiness Level 4 for the Cesium Nitric Acid Recovery Process System (CNP)

Complete	Criteria	Basis
Y	Cross technology issues (if any) have been fully identified	The engineering specification for the cesium nitric acid recovery system (24590-PTF-3PS-MEVV-T0002, Rev. 4) accounts for process operating requirements including factors such vapor-liquid equilibrium, pressure, temperature, and boil off rate. These have been evaluated and documented in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001, Rev. 001).
Y	Laboratory components tested are surrogates for system components	Laboratory components tested were surrogates for the following system components; reboiler (CNP-HX-0001), separator vessel and mist eliminator pad (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and recovered nitric acid vessel (CNP-VSL-00004). **However, the laboratory components tested did not include a surrogate for the rectifier column (CNP-DISTC-00001) present in the system components** (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B).
N	**Individual components tested in laboratory/by supplier (contractor's component acceptance testing)**	**Laboratory components tested were surrogates for the following system components; reboiler (CNP-HX-0001), separator vessel and mist eliminator/separator pad (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and recovered nitric acid vessel (CNP-VSL-00004).** **The laboratory components tested did not include a surrogate for the rectifier column (CNP-DISTC-00001) present in the system components (SCT-M0SRLE60-00-183-02, Rev. 00A, SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B).**
N/A	Subsystems composed of multiple components tested at lab-scale using simulants	Not applicable (N/A).
Y	Modeling and simulation used to simulate some components and interfaces between components	The OLI System Inc. Environmental Simulation model was used to simulate the CNP evaporator and condensers, but not the rectifier column (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D). Modeling was used to simulate mass and energy balances for all of the components of the CNP, including the rectifier column (CNP-DISTC-00001) (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B).
Y	Overall system requirements for end user's application are documented	System requirements are documented in the CNP system description (24590-PTF-3YD-CNP-00001) and the CNP engineering specification (24590-PTF-3PS-MEVV-T0002).
Y	System performance metrics measuring requirements have been established	System performance metrics have been established in the CNP system description (24590-PTF-3YD-CNP-00001) and the CNP engineering specification (24590-PTF-3PS-MEVV-T0002).
Y	Laboratory testing requirements derived from system requirements are established	Laboratory testing requirements and documentation of completion are provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001, Rev. 001).

Table C.1. (cont'd)

Complete	Criteria	Basis
Y	Available components assembled into laboratory-scale system	With the exception of the rectifier column, the laboratory-scale system simulated all major equipment components of the CNP (SCT-M0SRLE60-00-183-02, Rev. 00A, SCT-M0SRLE60-00-183-01, Rev. 00D, and SCT-M0SRLE60-00-185-01, Rev. 00B).
Y	Laboratory experiments with available components show that they work together (lab kludge)	The laboratory experiments demonstrated integration of the evaporator vessel/reboiler, mist eliminator/ separator pad and condensers components (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B). All components tested at the laboratory-scale were shown to work together.
Y	Analysis completed to establish component compatibility	Engineering calculations are completed to establish components compatibility, and integration. Subcontractor is conducting design of evaporator, reboiler, rectifier column, and condensers (24590-PTF-3YD-CNP-00001).
Y	Science and Technology exit criteria established	Science and Technology exit criteria and documentation of completion are provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001, Rev. 001).
N	**Technology demonstrates basic functionality in simulated environment**	**The functions of the CNP is concentrate to 80% saturation for the cesium eluate solution, recover 0.5 M nitric acid solution for re-use as eluent by the CXP (24590-PTF-3YD-CNP-00001), and achieve a cesium decontamination factor of 5,000,000 for the recovered nitric acid solution (24590-PTF-3PS-MEVV-T0002, Rev. 4, pg. 49).** **These functions have not been demonstrated.**
Y	Scalable technology prototypes have been produced	No scaling issues have been identified.
Y	Draft conceptual designs have been documented	The conceptual design is described in the CNP system description (24590-PTF-3YD-CNP-00001) and the CNP engineering specification (24590-PTF-3PS-MEVV-T0002).
Y	Equipment-scaleup relationships are understood/accounted for in technology development program	Equipment-scaleup relationships (e.g., heat capacities for various streams and nitric acid vapor-liquid equilibrium) were determined and documented (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B). Equipment-scaleup relationships were modeled in the mass and energy balance for the CNP (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B).
Y	Sufficient testing has been completed to define requirements for full-scale system.	Laboratory-scale testing and modeling is complete and used to define requirements for the full-scale system as defined in the CNP engineering specification (24590-PTF-3PS-MEVV-T0002).
Y	Controlled laboratory environment used in testing	Laboratory test conditions were defined and controlled as part of the CNP testing program, as documented in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001, Rev. 001) and test reports (SCT-M0SRLE60-00-183-02, Rev. 00A; SCT-M0SRLE60-00-183-01, Rev. 00D; SCT-M0SRLE60-00-185-01, Rev. 00B).

Table C.1. (cont'd)

Complete	Criteria	Basis
Y	Initial cost drivers identified	The estimated cost of the CNP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Integration studies have been started	The project has contracted with AREVA for detailed design and fabrication of all three forced circulation evaporator systems (FEP, TLP, and CNP). Lessons learned from the FEP and TLP will be applied to detailed design and fabrication of the CNP: reboiler (CNP-HX-0001), separator vessel and mist eliminator pad (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and the rectifier column (CNP-DISTC-00001).
Y	Formal risk management program initiated	The WTP Project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13).
Y	Key manufacturing processes for equipment systems identified	Equipment is envisioned to be a routine fabrication.
Y	Scaling documents and designs of technology have been completed	Equipment-scaleup relationships (e.g., heat capacities for various streams and nitric acid vapor-liquid equilibrium) were determined and documented (SCT-M0SRLE60-00-183-02, Rev. 00A, SCT-M0SRLE60-00-183-01, Rev. 00D, and SCT-M0SRLE60-00-185-01, Rev. 00B). Equipment-scaleup relationships were modeled in the mass and energy balance for the CNP (24590-QL-POA-MEVV-00002-08-00003, Rev. 00B).
Y	Key manufacturing processes assessed in laboratory	Equipment is envisioned to be a routine fabrication.
Y	Functional work breakdown structure developed (functions established)	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides a work breakdown structure and an integrated schedule showing how the CNP will be incorporated into the PT Facility.
Y	Low fidelity technology "system" integration and engineering completed in a lab environment	Laboratory components tested were surrogates for the following system components: reboiler (CNP-HX-0001), separator vessel and mist eliminator/separator pad (CNP-EVP-0001), condensers (CNP-HX-00002, CNP-HX-00003, and CNP-HX-00004), and recovered nitric acid vessel (CNP-VSL-00004). The laboratory components tested did not include a surrogate for the rectifier column (CNP-DISTC-00001) present in the system components (SCT-M0SRLE60-00-183-02, Rev. 00A, SCT-M0SRLE60-00-183-01, Rev. 00D, SCT-M0SRLE60-00-185-01, Rev. 00B).
Y	Mitigation strategies identified to address manufacturability/producibility shortfalls	Equipment is envisioned to be a routine fabrication.
Y	Technology availability dates established	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides a work breakdown structure and an integrated schedule showing how the CNP will be incorporated into the PT Facility.

Table C.2. Technology Readiness Level 6 for the Cesium Ion Exchange Process System (CXP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The performance of the ion exchange (IX) medium is summarized in the *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644* (24590-WTP-RPT-RT-06-001). A preliminary IX model, *Ion Exchange Modeling for Removal of Cesium from Hanford Waste Using Resorcinol-Formaldehyde Resin* (SCT-M0SRLE60-00-05-00003, Rev. 00A) has been prepared which demonstrates performance and behavior interactions of the IX system, including tradeoffs such as flow rate, column height, and diameter. A revision to the IX model is planned for issuance in May 2007 to reflect results of recent testing.
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1I). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The conceptual design of the equipment is complete. The final design and fabrication of equipment will be conducted under a subcontract. Most drawings and calculations are identified in the *System Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001, Rev. 0).
Y	Draft design drawings for final plant system are nearly complete	The conceptual design of the equipment is complete. The final design and fabrication of equipment will be conducted under a subcontract. Most drawings and calculations are identified in the *System Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001, Rev. 0).
Y	Operating environment for final system known	The operating environment for the CXP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1I), the S*ystem Description for the Cesium Ion Exchange Process – System CXP* (24590-PTF-3YD-CXP-00001, Rev. 0), the PT Facility PSAR (24590-WTP-PSAR-ESH-01-002-02, Rev. 2b), and *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets for the PT Facility have established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1I). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the CXP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering-scale similar system tested with a range of simulants	Testing was conducted at engineering-scale using tank 241-AP-101 simulant to evaluate relevant IX process parameters such as column diameter for scale-up and hydraulic performance (24590-WTP-RPT-RT-06-001).

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Modeling and Simulation used to simulate system performance in an operational environment	Modeling of the CXP using the latest test results is provided in *Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644* (24590-WTP-RPT-RT-06-001, Appendix A), which simulates system performance in an operational environment at nominal operating parameters (e.g., 25°C and 22 gpm feed flow rate). The preliminary IX model, *Ion Exchange Modeling for Removal of Cesium from Hanford Waste Using Resorcinol-Formaldehyde Resin* (SCT-M0SRLE60-00-05-00003, Rev. 00A) will need to be updated to reflect these test results and this update is planned to be completed by May 2007. Proposed new process conditions (e.g., 45 to 50°C and 30 gpm feed flow rate) to support operational changes in the UFP will need to be evaluated by the project.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	Prototypic 3, 12, and 24-inch diameter columns were tested with resorcinol formaldehyde resin to demonstrate full-scale column (48-inch diameter) hydraulic conditions to verify design features (24590-101-TSA-W000-0004-174-00002, Rev. 00B; SCT-M0SRLE60-00-110-00028). Resin addition and removal features were demonstrated in the 12-inch and 24-inch diameter prototypic columns (SCT-M0SRLE60-00-110-00028, pp. 116-120). Actual plant equipment will be fabricated by a subcontractor in accordance with engineering specification (24590-PTF-3PS-MWD0-T0005, Rev. 1), which needs to be revised. This engineering specification does not require prototypic column testing by the subcontractor to verify design features of the IX columns.
N	**Operating limits determined using engineering-scale system (from design, safety, environmental compliance)**	**Not completed. Initial operating limits have been established based for SuperLig 644 resin use in the IX columns and are included in the engineering specification (24590-PTF-3PS-MWD0-T0005, Rev. 1). However, this engineering specification needs to be revised to incorporate the normal use of 600 gallons of resorcinol formaldehyde resin instead of 415 gallons of SuperLig 644 resin; revision of column process data in Appendix A and resin properties in Appendix B for use of resorcinol formaldehyde resin; and requirements to prevent gas blinding of the resin retention screen during fluidized up-flow mode of operation and minimize gas bubble retention below the resin retention screen (see 24590-101-TSA-W000-0004-174-00002, Rev. 00B). The project plans to update this specification before resuming procurement of the IX columns.** **Operating limits for spherical resorcinol formaldehyde resin have been established as part of the engineering-scale testing conducted with prototypic columns (SCT-MOSRLE60-00-10-00005, Rev. 00A).**

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operational requirements document available	The minimum operating requirements for the CXP are defined in the WTP *Operations Requirements Document* (24590-WTP-RPT-OP-01-001, Rev. 2) and the CXP system description (24590-PTF-3YD-CXP-00001, Rev. 0).
N	**Off-normal operating responses determined for engineering-scale system**	**Engineering-scale hydraulic testing of the IX column containing spherical resorcinol formaldehyde resin explored a range of operating conditions that represented normal and off-normal conditions (SCT-M0SRLE60-00-110-00028). Reactivity of spherical resorcinol formaldehyde resin with 0.5 to 3 M concentrations of nitric acid solution in the temperature range of 25 to 66°C has been evaluated (SCT-MOSRL60-00-221-00001, Rev. 00A). Radiation (0 to 100 Mrad) and thermal (25 to 65°C) degradation testing has been completed with spherical resorcinol formaldehyde resin (SCT-MOSRLE60-00-10-00005, Rev. 00A).** **Physical degradation testing, such as osmotic shock and crushing, for irradiated, spherical resorcinol formaldehyde resin samples was not conducted (SCT-MOSRLE60-00-10-00005, Rev. 00A, pg. 4). Spherical resorcinol formaldehyde resin has shown no physical degradation during 14 cycles of chemical testing as part of the hydraulic tests using engineering-scale columns (SCT-M0SRLE60-00-110-00028, pg. 67).**
Y	System technical interfaces defined	Interfaces for the CXP are defined the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1I) and Section 9 the CXP system description (24590-PTF-3YD-CXP-00001, Rev. 0).
N	**Component integration demonstrated at an engineering-scale**	**Engineering-scale testing has been completed for the IX column, resin addition, and resin removal design features (SCT-MOSRLE60-00-10-00005, Rev. 00A). The design for managing hydrogen gas generation in the columns has not been demonstrated at the engineering-scale.** **Lab-scale testing with a 3-inch diameter column has shown gas blinding of the resin retention screen during fluidized up-flow mode of operation and gas bubble retention below the resin retention screen (see 24590-101-TSA-W000-0004-174-00002, Rev. 00B). The project plans to modify the IX column engineering specifications (24590-PTF-3PS-MWD0-T0005, Rev. 1) to mitigate these gas retention issues, but the specification does not currently require the subcontractor to conduct testing to verify suitability of the column design.**
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues have been identified.
Y	Analysis of project timing ensures technology will be available when required	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the CXP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Have begun to establish an interface control process	The interfaces between the CXP and the balance of the PT Facility are described in the CXP system description (24590-PTF-3YD-CXP-00001, Rev. 0). These include both physical and process interfaces with the PT Facility.
Y	Acquisition program milestones established for start of final design (CD-2)	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the CXP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	Equipment is envisioned to be a routine fabrication. The External Flowsheet Review Team (EFRT) identified an issue with the manufacture of the IX columns citing the need to ensure the subcontractor has suitable experience in design and fabrication of similar columns. Manufacturing production of the spherical resorcinol formaldehyde resin has been demonstrated by two vendors (24590-WTP-RPT-RT-06-001, Section 8.5).
Y	Most pre-production hardware is available to support fabrication of the system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
N	**Engineering feasibility fully demonstrated (e.g., will it work?)**	**Not completed. The design for managing hydrogen gas generation in the columns has not been demonstrated at the engineering-scale.** **Lab-scale testing with a 3-inch diameter column has shown gas blinding of the resin retention screen during fluidized up-flow mode of operation and gas bubble retention below the resin retention screen (see 24590-101-TSA-W000-0004-174-00002, Rev. 00B). The project plans to modify the IX column engineering specifications (24590-PTF-3PS-MWD0-T0005, Rev. 1) to mitigate these gas retention issues, but the specification does not currently require the subcontractor to conduct testing to verify suitability of the column design.**
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	**Technology "system" design specification complete and ready for detailed design**	**The engineering specification (24590-PTF-3PS-MWD0-T0005, Rev. 1) for the IX columns needs to be revised to incorporate the normal use of 600 gallons of resorcinol formaldehyde resin instead of 415 gallons of SuperLig 644 resin; revision of column process data in Appendix A and resin properties in Appendix B for use of resorcinol formaldehyde resin; and requirements to prevent gas blinding of the resin retention screen during fluidized up-flow mode of operation and minimize gas bubble retention below the resin retention screen (see 24590-101-TSA-W000-0004-174-00002, Rev. 00B). The project plans to update this specification before resuming procurement of the IX columns (24590-WTP-PL-ENG-06-0026, Rev. 000).** **Vendor drawings will be used to document the final design.**
Y	Components are functionally compatible with operational system	Functions of the components are defined in the engineering specification for the IX columns (24590-PTF-3PS-MWD0-T0005, Rev. 1).
N	**Engineering-scale system is high-fidelity functional prototype of operational system**	The engineering-scale system for the IX columns is a high-fidelity functional prototype of the operational system (SCT-M0SRLE60-00-110-00028, Rev. 00A), which demonstrated hydraulic features of the spherical resorcinol formaldehyde resin, resin pretreatment, loading, elution and regeneration, resin addition, and removal functions. **However, the engineering-scale system did not include design features for management of hydrogen gas generated from the IX columns and this system was not prototyped.**
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	Integration was demonstrated as part of the engineering-scale system for the IX columns (SCT-M0SRLE60-00-110-00028, Rev. 00A).
N	**Final Technical Report on Technology completed**	**Not completed. The final technical report will follow completion of Stage 2 (update of Verse code IX model report WSRC-TR-2004-00100) and Stage 3 (aging and storage) testing of the spherical resorcinol formaldehyde resin. The project expects to issue Stage 2 and Stage 3 test reports in May 2007. A closure report will then be prepared for the CXP.**

Table C.2. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
N	**Waste processing issues have been identified and major ones have been resolved**	**The effect(s) of anti-foaming agent (DOW Q2-318A) and other organic compounds expected to be present in the feed to the CXP have not been evaluated.** **Anti-foaming agent has not been included in any of the actual tank waste samples or simulants used in laboratory-scale column tests. A laboratory-scale column containing spherical resorcinol formaldehyde resin was tested with actual pretreated waste sample from tank 241-AN-102 (24590-101-TSA-W000-0004-1742-00001, Rev. 00A). The tank 241-AN-102 sample had been previously characterized to determine the concentration of various chelating organic compounds (PNWD-3229). Small-scale column tests were conducted with tank 241-AN-105 (oxalate, glycolic acid, acetate, and formate) simulant (24590-101-TSA-W000-0004-91-00003, Rev. 00A) and 241-AP-101 (oxalate, acetate, and formate) simulant included some of the organic compounds known to be present in Hanford tank wastes.** **However, these tests have not demonstrated the effects to the CXP from the anti-foaming agent, the range of organic compounds, including chelating organic compounds (e.g., tri-sodium hydroxy-ethylene-diamine-triacetate), nor separable organics (tri-butyl phosphate and normal paraffin hydrocarbon).** **The effect of separable organics on the process is required to be evaluated by WTP Contract, Standard 2: Research, Technology, and Modeling, item (3) (viii), Effect of Separable Organics (WTP Contract No. DE-AC27-01RV14136).**
Y	Process and tooling are mature to support fabrication of components/system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Production demonstrations are complete (at least one time)	Manufacturing production of the spherical resorcinol formaldehyde resin has been demonstrated by two vendors (24590-WTP-RPT-RT-06-001, Section 8.5). Other system components are commercially available or will be manufactured from commercially available components.

Table C.3. Technology Readiness Level 6 for the Waste Feed Evaporation Process System (FEP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the FEP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the FEP System to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if submerged bed scrubber (SBS) condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations. Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The final design of the equipment is in progress. Areva has been retained as the FEP evaporator designer.
Y	Draft design drawings for final plant system are nearly complete	The final design of the plant equipment is in progress. Most drawings and calculations are identified in the *System Description for Waste Feed Evaporation Process (FEP)* (24590-PTF-3YD-FEP-00001).
Y	Operating environment for final system known	The operating environment for the FEP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C), the FEP system description (24590-PTF-3YD-FEP-00001), the PT Facility PSAR (24590-WTP-PSAR-ESH-01-002-02, Rev. 2b) and *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i).

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets have been established in WTP Basis of Design (24590-WTP-DB-ENG-01-001, Rev. 1I). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the FEP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering-scale similar system tested with a range of simulants	Pilot-scale testing was performed in the Semi-Integrated Pilot Plant (SIPP) evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1 psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60^{o}C). The test results of the pilot-scale SIPP evaporator, when-scaled support the production rate goals equivalent to at least 30 gpm.
Y	Modeling and Simulation used to simulate system performance in an operational environment	The performance of the FEP has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The results of these assessments show that the FEP will support project requirements.
Y	Plan for demonstration of prototypical equipment and process testing completed, results verify design	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001). Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.
Y	Operating limits determined using engineering-scale system (from design, safety, environmental compliance)	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operational requirements document available	The minimum operating requirements for the FEP are defined in the WTP *Operations Requirements Document* (24590-WTP-RPT-OP-01-001, Rev. 2) and the FEP system description (24590-PTF-3YD-FEP-00001, Rev. 1).
Y	Off-normal operating responses determined for engineering-scale system	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the FEP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the FEP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations. Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	System technical interfaces defined	Interfaces for the FEP are defined the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C) and Section 9 of the FEP system description (24590-PTF-3YD-FEP-00001, Rev. 1).
Y	Component integration demonstrated at an engineering-scale	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C).
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues have been identified. Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). Equipment will be tested at full-scale during cold commissioning.

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Analysis of project timing ensures technology will be available when required	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the FEP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the FEP and the balance of the PT Facility are described in the FEP system description (24590-PTF-3YD-FEP-00001, Rev. 1). This includes both physical and process interfaces with the PT Facility.
Y	Acquisition program milestones established for start of final design (CD-2)	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the FEP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Most pre-production hardware is available to support fabrication of the system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Engineering feasibility fully demonstrated (e.g., will it work?)	Pilot-scale testing completed in the SIPP provided a basis for the demonstration of the feasibility of the FEP.
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Technology "system" design specification complete and ready for detailed design	The equipment system is being designed and is being fabricated. Vendor drawings will be used to document the final design. The design calculations to support detailed design prepared by BNI include: 24590-PTF-MEC-FEP-00001, Rev. B, *Process Data for Waste Feed Evaporator, Feed Vessels and Feed/Concentrate Pumps*, and 24590-PTF-MTC-FEP-00001, Rev. B, *Waste Feed Evaporator Feed Vessel (FEP-VSL-00017A/B)*. A preliminary design of the FEP was completed by BNI and is provided in the following documents: 24590-PTF-MV-FEP-00001, Rev. A, *Equipment Assembly Waste Feed Evaporator Feed Vessel FEPVSL-00017A (Q)*, and 24590-PTF-MV-FEP-00002, Rev. A, *Equipment Assembly Waste Feed Evaporator Feed Vessel FEPVSL-00017B (Q)*.
Y	Components are functionally compatible with operational system	Functions of the components are defined in the in the *System Description for Waste Feed Evaporation Process (FEP)* (24590-PTF-3YD-FEP-00001). Testing in the SIPP demonstrated the basic operation of the proposed equipment technology.
Y	Engineering-scale system is high-fidelity functional prototype of operational system	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression.

Table C.3. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Final Technical Report on Technology completed	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Waste processing issues have been identified and major ones have been resolved	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the FEP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the FEP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations.
Y	Process and tooling are mature to support fabrication of components/system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Production demonstrations are complete (at least one time)	This is envisioned to be a routine vessel and reboiler fabrication. No issues with the manufacturability of the equipment have been identified.

Table C.4. Technology Readiness Level 6 for the Treated LAW Evaporation Process System (TLP)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the TLP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the TLP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations. Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept.
Y	Frequent design changes occur	The final design of the TLP is in progress. Some engineering drawings and calculations are identified in the TLP system description (24590-PTF-3YD-TLP-00001).
Y	Draft design drawings for final plant system are nearly complete	The final design of the equipment has been completed. Most drawings and calculations are identified in the TLP system description (24590-PTF-3YD-TLP-00001).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Operating environment for final system known	The operating environment for the TLP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C), the TLP system description (24590-PTF-3YD-TLP-00001), the PT Facility PSAR (24590-WTP-PSAR-ESH-01-002-02, Rev. 2b) and *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the TLP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).
Y	Engineering-scale similar system tested with a range of simulants	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.
Y	Modeling and Simulation used to simulate system performance in an operational environment	The performance of the TLP has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The results of these assessments show that the TLP will support project requirements.

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Performance and behavior of subcomponent interactions understood (including tradeoffs)	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the TLP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the TLP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations. Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to close these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Reliability, Availability, Maintainability Index (RAMI) levels established	RAMI targets have been established in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Frequent design changes occur	Final design of equipment is completed. Most drawings and calculations are identified in the TLP system description (24590-PTF-3YD-TLP-00001).
Y	Draft design drawings for final plant system are nearly complete	The final design of the plant equipment is in progress. Most drawings and calculations are identified in the *System Description for Treated LAW Evaporation Process (TLP)* (24590-PTF-3YD-TLP-00001).
Y	Operating environment for final system known	The operating environment for the TLP is specified in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C), the TLP system description (24590-PTF-3YD-TLP-00001), the PT Facility PSAR (24590-WTP-PSAR-ESH-01-002-02, Rev. 2b) and *Safety Envelope Document; PT Facility Specific Information* (24590-WTP-SED-ENS-03-002-02, Rev. 1i).
Y	Collection of actual maintainability, reliability, and supportability data has been started	RAMI targets for LAW Vitrification Facility have been established in WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C). The *2005 WTP Operational Research Assessment Report* (24590-WTP-RPT-PO-05-001, Rev. 0) documents acceptability of the design concept. This information is based on testing results of similar equipment and literature reviews of applicable designs.
Y	Estimated cost of the system design is identified	The cost of the TLP is provided in the *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Engineering-scale similar system tested with a range of simulants	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.
Y	Modeling and Simulation used to simulate system performance in an operational environment	The performance of the TLP has been modeled using the Tank Utilization Assessment Model (24590-WTP-RPT-PO-05-008, Rev. 0) and the Mass Balance Model (24590-WTP-RPT-PO-05-009, Rev. 0). The results of these assessments show that the TLP will support project requirements.
Y	Plan for and process testing completed, results verify design	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001). Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). The test results of the pilot-scale SIPP evaporator, when scaled support the production rate goals equivalent to at least 30 gpm.
Y	Operating limits determined using engineering-scale system	Operating limits for process system have been estimated from pilot-scale testing performed in the SIPP evaporation system. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). Operational parameters during full-scale will be tested at cold commissioning.
Y	Operational requirements document available	The minimum operating requirements for the TLP are defined in the WTP *Operations Requirements Document* (24590-WTP-RPT-OP-01-001, Rev. 2) and the FEP system description (24590-PTF-3YD-FEP-00001, Rev. 1).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Off-normal operating responses determined for engineering-scale system	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the TLP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the TLP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations.
Y	System technical interfaces defined	Interfaces for the TLP are defined in the WTP *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 1C) and Section 9 of the TLP system description (24590-LAW-3YD-LFH-00001, Rev. 1).
Y	Component integration demonstrated at an engineering-scale	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C).
Y	Scaling issues that remain are identified and supporting analysis is complete	No scaling issues have been identified. Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression. The test system is operated at conditions comparable to the actual process at ~ 1psia at the solution surface; the steam heat is introduced in a shell and tube heat exchanger to bring the solutions to boiling temperature (40 to 60°C). Equipment will be tested at full-scale during cold commissioning.
Y	Analysis of project timing ensures technology will be available when required	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the TLP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Have begun to establish an interface control process	The interfaces between the TLP and the balance of the PT Facility are described in the TLP system description (24590-PTF-3YD-TLP-00001). This includes both physical and process interfaces with the PT Facility.

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Acquisition program milestones established for start of final design (CD-2)	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001, Rev. 0) provides an integrated schedule showing how the TLP technology will be incorporated into the PT Facility. Technology availability does not constrain this schedule.
Y	Critical manufacturing processes prototyped	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Most pre-production hardware is available to support fabrication of the system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Engineering feasibility fully demonstrated (e.g., will it work?)	Pilot-scale testing completed in the SIPP provided a basis for the demonstration of the feasibility of the TLP.
Y	Materials, process, design, and integration methods have been employed (e.g., can design be produced?)	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Technology "system" design specification complete and ready for detailed design	The equipment system is being designed and is being fabricated. Vendor drawings will be used to document the final design. A preliminary design of the TLP was completed by BNI and is referenced in the system description.
Y	Components are functionally compatible with operational system	Functions of the components are defined in the in the *System Description for Treated LAW Evaporation Process (TLP)* (24590-PTF-3YD-TLP-00001). Testing in the SIPT demonstrated the basic operation of the proposed equipment technology.
Y	Engineering-scale system is high-fidelity functional prototype of operational system	Pilot-scale testing was performed in the SIPP evaporation system. The SIPP pilot-scale evaporator is a 1/76-scale in terms of cross sectional area. All hydraulic head conditions are full-scale in order to control the vacuum seal requirement and boiling point suppression.
Y	Formal configuration management program defined to control change process	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Integration demonstrations have been completed (e.g., construction of testing system)	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).

Table C.4. (cont'd)

Criteria Satisfied (Y/N)	Criteria	Basis for Completion
Y	Final Technical Report on Technology completed	Testing of lab-scale and pilot-scale evaporation systems was completed by the Westinghouse Savannah River Company (WSRC) to closure these issues. A summary of the basis for the closure of these issues is provided in the *Closure Report for R&T Evaporator Studies* (24590-PTF-RPT-RT-03-001).
Y	Waste processing issues have been identified and major ones have been resolved	The WTP R&T Program Plan (24590-WTP-PL-RT-01-002) for testing of the TLP Evaporator concept was aimed at addressing nine issues, stated below: • Ability of the TLP to meet design basis operating and throughput requirements. • Evaluate the affect of trace organics on the evaporator operations. • Determine the operating impacts from recycle streams. • Determine the offgas compositions for regulatory purposes. • Demonstrate process-scale-up. • Evaluate waste foaming in the evaporator. • Evaluate aluminum silicate plate-out in the evaporator. • Evaluate if SBS condensate returns produce uranium precipitates. • Evaluate if dimethyl mercury forms in evaporator operations.
Y	Process and tooling are mature to support fabrication of components/system	This is envisioned to be a routine fabrication. No issues with the manufacturability of the equipment have been identified.
Y	Production demonstrations are complete (at least one time)	This is envisioned to be a routine vessel and reboiler fabrication. No issues with the manufacturability of the equipment have been identified.

Table C.5. Technology Readiness Level 4 Summary for the Ultrafiltration Process System (UFP)

Complete	Criteria	Basis
Y	Cross technology issues (if any) have been fully identified	The UFP system description (24590-PTF-3YD-0001, Rev. 0) and *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 0) describe process operating requirements and identify cross technology issues.
Y	Laboratory components tested are surrogates for system components	SIPP and cells unit filter (CUF) tests on a variety of wastes demonstrates basic functionality of ultrafilters, caustic leaching, and washing, (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756). Basic functionality for oxidative leaching is demonstrated (WTP-RPT-117, WTP-RPT-137).
Y	Individual components tested in laboratory/by supplier (contractor's component acceptance testing)	SIPP and CUF tests tested ultrafilters (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
N	**Subsystems composed of multiple components tested at lab-scale using simulants**	**Completed for ultrafilters (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756); not completed for oxidative leaching.**
Y	Modeling and simulation used to simulate some components and interfaces between components	G-2 modeling runs have been carried out in the design evaluation supporting resolution of EFRT issue M-12 (24590-WTP-RTP-ENG-06-014).
Y	Overall system requirements for end user's application are documented	Section C of the WTP contract defines throughputs and other requirements.
Y	System performance metrics measuring requirements have been established	Section C of the WTP contract defines throughputs and other requirements.
Y	Laboratory testing requirements derived from system requirements are established	Test plans are documented for all testing; e.g., see WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756; WTP-RPT-117; WTP-RPT-137.
Y	Available components assembled into laboratory-scale system	Ultrafilter test systems (CUF and SIPP) have been assembled (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
Y	Laboratory experiments with available components show that they work together (lab kludge)	Ultrafilter test systems (CUF and SIPP) have been assembled (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
Y	Analysis completed to establish component compatibility	Ultrafilter test systems (CUF and SIPP) have been assembled (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
N	**Science and Technology exit criteria established**	**Exit criteria are established in the M12/13 Issue Response Plans for caustic leaching and ultrafilters. No exit criteria established for oxidative leaching.**

Table C.5. (cont'd)

Complete	Criteria	Basis
Y	Technology demonstrates basic functionality in simulated environment	SIPP and CUF tests on a variety of wastes demonstrates basic functionality of ultrafilters, caustic leaching, and washing (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756). Basic functionality for oxidative leaching is demonstrated (WTP-RPT-117; WTP-RPT-137).
Y	Scalable technology prototypes have been produced	Ultrafilter test systems (SIPP and CUF) have been produced and used (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756).
Y	Draft conceptual designs have been documented	The M12/M13 engineering studies have document conceptual designs 24590-WTP-RPT-ENG-06-011 and -014.
N	**Equipment-scaleup relationships are understood/accounted for in technology development program**	**Ultrafilter scalability not demonstrated (WSRC-TR-2005-00105; WSRC-MS-2005-00756). Mixing scalability not demonstrated (Report of the External Flowsheet Review Team, March 2006).**
Y	Controlled laboratory environment used in testing	Testing documented for ultrafilters, caustic leaching, and washing (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756) and oxidative leaching (WTP-RPT-117, WTP-RPT-137)
Y	Initial cost drivers identified	The *May 2006 Estimate at Completion* (24590-WTP-CE-PC-06-001) provides a baseline estimate of UFP costs. BNI is developing trends for upgrades of UFP.
Y	Integration studies have been started	Some studies for ultrafilters, caustic leaching, and washing (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756) and oxidative leaching (WTP-RPT-117; WTP-RPT-137) have been completed. M12/13 studies have been started.
Y	Formal risk management program initiated	WTP Project has established a WTP Risk Management Plan (24590-WTP-RPT-PR-01_006).
Y	Key manufacturing processes for equipment systems identified	Ultrafilters and other UFP components have been manufactured.
N	**Scaling documents and designs of technology have been completed**	**Designs exist but scalability of filters and mixing processes has not been demonstrated (WSRC-TR-2005-00105; WSRC-MS-2005-00756, Report of the External Flowsheet Review Team, March 2006).**
Y	Key manufacturing processes assessed in laboratory	Ultrafilters and other UFP components have been manufactured.
Y	Functional work breakdown structure developed (functions established)	The *System Description for Ultrafiltration Process System (UFP)* (24590-PTF-3YD-UFP-0001, Rev. 0) and *Basis of Design* (24590-WTP-DB-ENG-01-001, Rev. 0) establish the UFP functions.

Table C.5. (cont'd)

Complete	Criteria	Basis
N	**Low fidelity technology "system" integration and engineering completed in a lab environment**	**Laboratory system integration exists for ultrafilters, caustic leaching, and washing (WTP-RPT-151; WSRC-TR-2005-00105; WSRC-TR-2003-0204; WSRC-MS-2005-00756), but not for and oxidative leaching (WTP-RPT-117; WTP-RPT-137).**
Y	Mitigation strategies identified to address manufacturability/producibility shortfalls	Ultrafilters and other UFP components have been manufactured.
N	**Technology availability dates established**	**A date (June 2008) has been established for ultrafiltration, washing, and caustic leaching in the M12/13 Issue Resolution Plans. None exists for oxidative leaching.**

Table C.6. Technology Readiness Level 5 Summary for the Pulse Jet Mixers (PJM)

Complete	Criteria	Basis
N	**Cross technology effects (if any) have been fully identified (e.g., system internally consistent)**	**Extensive testing has been completed to support the PJM mixing technology for the five high-solids containing vessels and the parameters that affect their performance. No testing has been completed to assess operational parameters for lower solids containing vessels.** **There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed do not sufficiently describe the test conditions and/or simulant characteristics that allow a comparison between the test conditions and the design. The Computational Fluid Dynamic (CFD) bench marking evaluations were not based on test conditions that are traceable to the low-solids content waste streams.** **The testing of high solids containing slurries has been exhaustive and is described in detail in *Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019). However, this testing has been focused on hydrogen release and not on meeting other important requirements of the vessel designs. This testing is incomplete based on a review and evaluation of the requirements identified in several project documents described below.**
Y	Plant size components available for testing	Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9- to 1/2-scale. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, zone of influence (ZOI), aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests.
Y	System interface requirements known (how will system be integrated into the plant?)	The PJM and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.

Table C.6. (cont'd)

Complete	Criteria	Basis
N	System requirements flow down through work breakdown structure (design engineering begins)	The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation. The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows: • Re-suspend settled solids and maintain suspension of solids within vessels, • Provide blending of cold chemicals with active process liquids, • Sufficiently mix the contents of the vessels for sampling, and • Provide for the blending of cold chemicals with water for dilution. Detailed requirements, useful for design are not presented consistently in various documents or consistently.
N	Requirements for technology verification established	Currently issues exist on the ability of the PJMs to meet basic mixing requirements. A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries: • The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling and less attention on Newtonian slurries with low solids concentrations that settle rapidly. • Larger denser particles may be more difficult to suspend that those used in the current design, and may be difficult to re-suspend. • The zone of influence (ZOI) for the PJMs in Newtonian vessels may be overestimated for large, dense, rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is questionable. • The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems, and may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results. In response to these issues, the WTP Contractor has prepared an Issue Response Plan for M3 "Inadequate Mixing System Design" (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries. In this Issue Response Plan, the WTP Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear. "Distinction between Newtonian and non-Newtonian has been based on anticipated solids

Table C.6. (cont'd)

Complete	Criteria	Basis
		concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (>20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity." **A test plan to support an evaluation of the PJMs has not been prepared and approved.**
Y	Lab-scale similar system tested with limited range of actual wastes, if applicable	A range of test platforms was tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three-scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing-scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
N	**Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)**	**Testing was completed on a 1/2-scale testing system to represent the UFP 02 vessels. No realistic testing has been completed to evaluate the PJM performance for low solids containing slurries.**
Y	Significant engineering and design changes	The design of the PJMs and PJM support systems has not been completed. Additional work is in progress on the FRP vessels and selected HLP and PWD vessels.
Y	Prototypes of equipment system components have been created (know how to make equipment)	A range of test platforms was tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three-scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing-scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	Fabrication of the PJMs and supporting equipment (jet pump pairs) is routine.
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	A range of test platforms was tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three-scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Manufacturing techniques have been	Fabrication of the PJMs and supporting equipment (jet pump pairs) is routine.

Table C.6. (cont'd)

Complete	Criteria	Basis
	defined to the point where largest problems defined	
N	**Lab-scale similar system tested with range of simulants**	**A range of test platforms was tested to evaluate PJM Scaling Relationships for high solids containing fluids. Tests were conducted in three-scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	Test platforms used for PJM evaluation have become more representative of the plant system as they have increased in-scale.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	PJM mixing systems that require redundancy in air and ventilation supplies to ensure operations for safety (e.g., hydrogen release) have been identified.
Y	Some special purpose components combined with available laboratory components for testing	The jet pump pair used to control operations of the PJM is the only special purpose component. In general, a valving arrangement was used to simulate operations of the jet pump pair.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	The PJM design is an integral part of the vessel design and is designed with the vessel. All PJM mixed vessel have been designed.
Y	Laboratory environment for testing modified to approximate operational environment	A range of test platforms was tested to evaluate PJM Scaling Relationships for high solids containing fluids. Tests were conducted in three-scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, ¼-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for-scaled testing. The technical basis for testing-scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. No testing has been completed for lower solids containing fluids.
Y	Component integration issues and requirements identified	Integration issues between the PJM, vessel and plant are identified the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.
Y	Detailed design drawings have been completed to support specification of	Pilot testing systems have been established to assess the mixing of high solids slurries. Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale.

Table C.6. (cont'd)

Complete	Criteria	Basis
	pilot testing system	
N	**Requirements definition with performance thresholds and objectives established for final plant design**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Preliminary technology feasibility engineering report completed**	***Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels.** **The technology feasibility of the low solids containing vessels has not been established through an experimental program.**
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	A range of test platforms was tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three-scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan in place	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work

Table C.6. (cont'd)

Complete	Criteria	Basis
		processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	The WTP project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13)
N	Individual process and equipment functions tested to verify that they work (e.g., test reports)	A range of test platforms was tested to evaluate PJM Scaling Relationships for high solids containing fluids. Tests were conducted in three-scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. No testing has been completed for lower solids containing fluids.

Table C.7. Technology Readiness Level 5 for the Waste Feed Receipt Process System (FRP)

Complete	Criteria	Basis
N	**Cross technology effects (if any) have been fully identified (e.g., system internally consistent)**	**Extensive testing has been completed to support the PJM mixing technology for the five high-solids containing vessels (HLP and UFP) and the parameters that affect their performance. No testing has been completed to assess operational parameters for lower solids containing vessels (FRP).** **There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed do not sufficiently describe the test conditions and/or simulant characteristics that allow a comparison between the test conditions and the design. The Computational Fluid Dynamic (CFD) bench marking evaluations were not based on test conditions that are traceable to the low-solids content waste streams.** **CFD analysis completed as early as August 2003 (24590-PTF-RPT-M-03-016) indicated that the FRP vessels would not adequately mix waste with an assumed set of properties. This analysis assumed that the waste properties had the following characteristics: solids content-3 wt%, solids density-2.9, particle size-22 micron, liquid specific gravity-1.2, viscosity at 25°C-2.94 cP with Newtonian fluid characteristics. This analysis indicated that the 8 mps PJM drive velocity (normal velocity when the vessel is full) may not be adequate to move the largest particles from the bottom of the vessels and the 12 mps drive velocity (normal velocity when the vessel is full) is recommended to keep large particles in suspension.** **A subsequent FRP mixing system analysis completed in March 2007 (24590-WTP-RPT-PR-07-002) indicated that the PJM designs will not meet the off-bottom suspension criteria at all FRP vessel levels even when the PJM are operated at 12 mps discharge velocity. This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be: density of liquid 1.1, density of solid-2.9, particle size 210 micron and a maximum of 3.8 wt% solids. This analysis also recommended that testing be completed to verify the adequacy of the PJM design for the FRP vessels. The analysis using the BHR Group correlation is based on a steady jet and does not account for fluid viscosity. Thus, the results can only be considered indicative and the system may not perform as well as expected.**

Table C.7. (cont'd)

Complete	Criteria	Basis
Y	Plant size components available for testing	Nine different test stands were constructed for the phases of the-scaled PJM testing and range from 1/9 to 1/2-scale of the UFP vessel. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, zone of influence (ZOI), aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests.
Y	System interface requirements known (how will system be integrated into the plant?)	The pulse jet mixer and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Interfaces with the FRP are described in the *System Description for Waste Feed Receipt Process (FRP)* (24590-PTF-3YD-FRP-00001).
N	**System requirements flow down through work breakdown structure (design engineering begins)**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents.**

Table C.7. (cont'd)

Complete	Criteria	Basis
N	**Requirements for technology verification established**	**Currently issues exist on the ability of the PJMs to meet basic mixing requirements. A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:** • **The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling and less attention on Newtonian slurries with low solids concentrations that settle rapidly.** • **Larger denser particles may be more difficult to suspend that those used in the current design, and may be difficult to re-suspend.** • **The zone of influence (ZOI) for the PJMs in Newtonian vessels may be overestimated for large dense rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is questionable.** • **The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems and may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results.** **In response to these issues, the WTP Contractor has prepared an Issue Response Plan for M3, "Inadequate Mixing System Design" (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries. In this Issue Response Plan, the WTP Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear.** **"Distinction between Newtonian and non-Newtonian has been based on anticipated solids concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (>20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity."**

Table C.7. (cont'd)

Complete	Criteria	Basis
N	**Lab-scale similar system tested with limited range of actual wastes, if applicable**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **The test platforms to evaluate the HLP-VSL-00022 have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
Y	**Interfaces between components/ subsystems in testing are realistic (benchtop with realistic interfaces)**	**The test platforms to evaluate the HLP-VSL-00022 have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
NA	Significant engineering and design changes	The design of the PJMs and PJM support systems has been completed for the FRP vessels.
Y	Prototypes of equipment system components have been created (know how to make equipment)	The FRP vessels have been fabricated.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	The FRP vessels have been fabricated.
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess FRP vessel design.
Y	Manufacturing techniques have been defined to the point where largest problems defined	The FRP vessels have been fabricated.

Table C.7. (cont'd)

Complete	Criteria	Basis
N	**Lab-scale similar system tested with range of simulants**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	Test platforms used for PJM evaluation have become more representative of the plant system as they have increased in-scale.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	PJM mixing systems that require redundancy in air and ventilation supplies to ensure operations for safety (e.g., hydrogen release) have been identified.
Y	Some special purpose components combined with available laboratory components for testing	The jet pump pair used to control operations of the PJM is the only special purpose component. In general, a valving arrangement was used to simulate operations of the jet pump pair.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	The FRP vessels have been fabricated.
Y	Laboratory environment for testing modified to approximate operational environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess FRP vessel design.
Y	Component integration issues and requirements identified	Integration issues between the PJM, vessel and plant are identified the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.
Y	Detailed design drawings have been completed to support specification of pilot testing system	Pilot testing systems have been established to assess the mixing of high solids slurries. Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale.

Table C.7. (cont'd)

Complete	Criteria	Basis
N	**Requirements definition with performance thresholds and objectives established for final plant design**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Preliminary technology feasibility engineering report completed**	***Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels.** **The technology feasibility of the low solids containing vessels has not been established through an experimental program.**
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan in place	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).

Table C.7. (cont'd)

Complete	Criteria	Basis
Y	Risk management plan documented	The WTP project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13)
N	**Individual process and equipment functions tested to verify that they work (e.g., test reports)**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**

Table C.8. – Technology Readiness Level 5 for the HLW Lag Storage and Feed Blending Process System (HLP)

Complete	Criteria	Basis
N	**Cross technology effects (if any) have been fully identified (e.g., system internally consistent)**	**Extensive testing has been completed to support the PJM mixing technology for the five high-solids containing vessels (HLP and UFP) and the parameters that affect their performance.** **No testing has been completed to assess operational parameters for lower solids containing vessels (HLP-VSL-00022).** **There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed do not sufficiently describe the test conditions and/or simulant characteristics that allow a comparison between the test conditions and the design. The Computational Fluid Dynamic (CFD) bench marking evaluations were not based on test conditions that are traceable to the low-solids content waste streams.** **An HLP-VSL-00022 mixing system analysis completed in March 2007 (24590-WTP-RPT-PR-07-002) indicated that the PJM designs will not meet the off-bottom suspension criteria for all vessel levels even when the PJM are operated at 12 mps discharge velocity. This analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be: density of liquid 1.1, density of solid-2.9, particle size 210 micron and a maximum of 16.7 wt% solids (Contract value). The analysis using the BHR Group correlation is based on a steady jet and does not account for fluid viscosity. Thus, the results can only be considered indicative and the system may not perform as well as expected.**
Y	Plant size components available for testing	Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale of the UFP vessel. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, zone of influence (ZOI), aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests. Modification of the test stands may be required to represent vessel HLP-VSL-00022.

Table C.8 (cont'd)

Complete	Criteria	Basis
Y	System interface requirements known (how will system be integrated into the plant?)	The pulse jet mixer (PJM) and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Interfaces with the HLP are described in the system description (24590-PTF-3YD-HLP-00001).
N	**System requirements flow down through work breakdown structure (design engineering begins)**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents.**
N	**Requirements for technology verification established**	**Currently issues exist on the ability of the PJMs to meet basic mixing requirements. A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:** • **The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling and less attention on Newtonian slurries with low solids concentrations that settle rapidly.** • **Larger denser particles may be more difficult to suspend that those used in the current design, and may be difficult to re-suspend.** • **The Zone of Influence (ZOI) for the PJMs in Newtonian vessels may be over estimated for large dense rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is questionable.** • **The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems and may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results.**

Table C.8 (cont'd)

Complete	Criteria	Basis
		In response to these issues, the WTP Contractor has prepared an Issue Response Plan for M3, "Inadequate Mixing System Design" (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries. In this Issue Response Plan, the WTP Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear. **"Distinction between Newtonian and non-Newtonian has been based on anticipated solids concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (>20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity."**
N	**Lab-scale similar system tested with limited range of actual wastes, if applicable**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **The test platforms to evaluate HLP-VSL-00022 has not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
N	**Interfaces between components/ subsystems in testing are realistic (benchtop with realistic interfaces)**	**The test platforms to evaluate the HLP vessels have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
Y	Significant engineering and design changes	The design of HLP vessels is not final because of outstanding issues on erosion wear of the vessel bottom caused by the PJMs and the capability of the HLP-VSL-00022 to adequately mix fluids.
Y	Prototypes of equipment system components have been created (know how to make equipment)	The HLP vessels are in a fabrication stage and no significant fabrication issues have been identified.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	The HLP vessels are in a fabrication stage and no significant fabrication issues have been identified.

Table C.8 (cont'd)

Complete	Criteria	Basis
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess HLP vessel design.
Y	Manufacturing techniques have been defined to the point where largest problems defined	The HLP vessels are in a fabrication stage and no significant fabrication issues have been identified.
N	**Lab-scale similar system tested with range of simulants**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	Test platforms used for PJM evaluation have become more representative of the plant system as they have increased in scale.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	PJM mixing systems that require redundancy in air and ventilation supplies to ensure operations for safety (e.g., hydrogen release) have been identified.
Y	Some special purpose components combined with available laboratory components for testing	The jet pump pair used to control operations of the PJM is the only special purpose component. In general, a valving arrangement was used to simulate operations of the jet pump pair.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	The HLP vessels are in a fabrication stage and no significant fabrication issues have been identified.

Table C.8 (cont'd)

Complete	Criteria	Basis
Y	Laboratory environment for testing modified to approximate operational environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess HLP vessel design.
Y	Component integration issues and requirements identified	Integration issues between the PJM, vessel, and plant are identified the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.
Y	Detailed design drawings have been completed to support specification of pilot testing system	Pilot testing systems have been established to assess the mixing of high solids slurries. Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale.
N	**Requirements definition with performance thresholds and objectives established for final plant design**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Preliminary technology feasibility engineering report completed**	***Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels.** **The technology feasibility of the low solids containing vessels has not been established through an experimental program.**

Table C.8 (cont'd)

Complete	Criteria	Basis
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan in place	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	The WTP project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13)
N	**Individual process and equipment functions tested to verify that they work (e.g., test reports)**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4 PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**

Table C.9 - Technology Readiness Level 5 for the Plant Wash and Disposal System (PWD)/ Radioactive Liquid Waste Disposal System (RLD)

Complete	Criteria	Basis
N	**Cross technology effects (if any) have been fully identified (e.g., system internally consistent)**	**Extensive testing has been completed to support the PJM mixing technology for the five high-solids containing vessels (HLP and UFP) and the parameters that affect their performance. No testing has been completed to assess operational parameters for lower solids containing vessels (PWD/RLD).** **There is no clear and complete data that indicates that the PJM technology will work with low-solids content slurries. Technology reports that have been completed do not sufficiently describe the test conditions and/or simulant characteristics that allow a comparison between the test conditions and the design. The Computational Fluid Dynamic (CFD) bench marking evaluations were not based on test conditions that are traceable to the low-solids content waste streams.** **An assessment in March 2007 (24590-WTP-RPT-PR-07-002) of the ability of the PWD and RLD vessels has identified that PWD-VSL-00044 will fail the off-bottom suspension criteria and that PWD-VSL-00033 and PWD-VSL-00043 will only marginally meet the off-bottom suspension criteria for 50/50 mixing (condition that assumes that one half of the PJMs are operating at a time). This additional analysis used a correlation for mixing provided by BHR Group Limited (FMP 064) that provided guidance on the sizing of fluid jets (e.g., applicable to PJM nozzle and discharge sizing) to suspend solids. The analyses also assumed that the fluid properties would be: density of liquid 1.1, density of solid-2.9, particle size 210 micron. The solids concentration was not specified. This analysis recommended that the discharge velocity of the PJMs be increased from 8 mps to 12 mps. Testing was also recommended to verify the adequacy of the PJMs in the aforementioned vessels.**
Y	Plant size components available for testing	Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale of the UFP vessel. Tests performed in these test stands included cavern size and breakthrough (where the top of cavern reaches the surface), mixing, sparging (introducing air bubbles at a low level through multiple points), and gas retention and release (GR&R). Mixing tests investigated mixing effectiveness, time to mix, solids suspension, and slurry velocity distribution. Sparging tests included determination of the size of the region of bubbles, zone of influence (ZOI), aerosol generation, and velocity distributions. Tests were also conducted in a bench-scale bubble column investigating the holdup characteristics of different gases and simulants and mass transfer stripping during sparging. Many novel instrumentation methods and analysis approaches were deployed for these tests.

Table C.9. (cont'd)

Complete	Criteria	Basis
Y	System interface requirements known (how will system be integrated into the plant?)	The Pulse Jet Mixer (PJM) and vessel sparging systems are described in the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Interfaces with the PWD/RLD are described in the *System Description for Plant Wash and Disposal System PWD and Radioactive Liquid Waste Disposal System RLD* (24590-PTF-3YD-PWD-00001).
N	**System requirements flow down through work breakdown structure (design engineering begins)**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The Basis of Design (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents.**
N	**Requirements for technology verification established**	**Currently issues exist on the ability of the PJMs to meet basic mixing requirements. A recent review of the WTP flowsheet (CCN:132846) has identified the following concerns associated with the use of PJMs to support mixing of Newtonian slurries:** • **The design of the PJM mixing systems has focused on non-Newtonian slurries that exhibit hindered settling and less attention on Newtonian slurries with low solids concentrations that settle rapidly.** • **Larger denser particles may be more difficult to suspend that those used in the current design, and may be difficult to re-suspend.** • **The zone of influence (ZOI) for the PJMs in Newtonian vessels may be over estimated for large dense rapidly settling particles. Without experimental data to support the ZOI estimates, the capability of the design to support solids suspension is questionable.** • **The computational fluid dynamics analysis of the PJM mixing systems has been based on continuous flow in two-phase systems and may not be sufficiently validated for the dynamics of PJM operation and needs to be matched to relevant experimental results.**

Table C.9. (cont'd)

Complete	Criteria	Basis
		In response to these issues, the WTP Contractor has prepared an Issue Response Plan for M3, "Inadequate Mixing System Design" (24590-WTP-PL-ENG-06-013) that describes a strategy to resolve issues on mixing of PJMs for vessels believed to contain Newtonian slurries. In this Issue Response Plan, the WTP Contractor has acknowledged that the distinction between Newtonian and non-Newtonian fluids may not be clear. **"Distinction between Newtonian and non-Newtonian has been based on anticipated solids concentrations of the waste in vessels. It is recognized that non-Newtonian solutions could contain low solids concentrations and have relatively high viscosities, and conversely, can have relatively high solids content with low viscosity (>20 cP). Thus both Newtonian and non-Newtonian fluids will be evaluated in the testing program, and will account for variations in solids loading and viscosity."**
N	**Lab-scale similar system tested with limited range of actual wastes, if applicable**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **The test platforms to evaluate the PWD/RLD vessels have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
N	**Interfaces between components/subsystems in testing are realistic (benchtop with realistic interfaces)**	**The test platforms to evaluate the PWD/RLD vessels have not been identified because the test plan to support an evaluation of the PJMs has not been prepared and approved.**
NA	Significant engineering and design changes	The design of the PJMs and PJM support systems has not been completed for the FRP vessels.
Y	Prototypes of equipment system components have been created (know how to make equipment)	Selected PWD and RLD vessels have been fabricated. Vessels in fabrication are RLD-VSL-00007, RLD-VSL-00008, and PWD-VSL-00044.
Y	Tooling and machines demonstrated in lab for new manufacturing processes to make component	Selected PWD and RLD vessels have been fabricated. Vessels in fabrication are RLD-VSL-00007, RLD-VSL-00008, and PWD-VSL-00044.

Table C.9. (cont'd)

Complete	Criteria	Basis
Y	High-fidelity lab integration of system completed, ready for test in relevant environments	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess PWD/RLD vessel design.
Y	Manufacturing techniques have been defined to the point where largest problems defined	Selected PWD and RLD vessels have been fabricated. Vessels in fabrication are RLD-VSL-00007, RLD-VSL-00008, and PWD-VSL-00044.
N	**Lab-scale similar system tested with range of simulants**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**
Y	Fidelity of system mock-up improves from laboratory to bench-scale testing	Test platforms used for PJM evaluation have become more representative of the plant system as they have increased in scale.
Y	Reliability, Availability, Maintainability Index (RAMI) target levels identified	PJM mixing systems that require redundancy in air and ventilation supplies to ensure operations for safety (e.g., hydrogen release) have been identified.
Y	Some special purpose components combined with available laboratory components for testing	The jet pump pair used to control operations of the PJM is the only special purpose component. In general, a valving arrangement was used to simulate operations of the jet pump pair.
Y	Three dimensional drawings and piping and instrumentation diagrams (P&ID) have been prepared	Selected PWD and RLD vessels have been fabricated. Vessels in fabrication are RLD-VSL-00007, RLD-VSL-00008, and PWD-VSL-00044.

Table C.9. (cont'd)

Complete	Criteria	Basis
Y	Laboratory environment for testing modified to approximate operational environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430. The current test platforms will likely be used to obtain technology information to assess PWD/RLD vessel design.
Y	Component integration issues and requirements identified	Integration issues between the PJM, vessel and plant are identified the *System Description for Pulse Jet Mixers and Supplemental Mixing Subsystems* (24590-WTP-3YD-50-00003). Integration of the PJM designs are an integral part of each vessel system (e.g., FRP, HLP, FEP) as described in the respective systems descriptions.
Y	Detailed design drawings have been completed to support specification of pilot testing system	Pilot testing systems have been established to assess the mixing of high solids slurries. Nine different test stands were constructed for the phases of the scaled PJM testing and range from 1/9 to 1/2-scale.
N	**Requirements definition with performance thresholds and objectives established for final plant design**	**The requirements for the performance of the PJM mixing equipment system are not clearly and completely addressed in the design documentation.** **The *Basis of Design* (24590-WTP-DB-ENG-01-001) delineates upper level requirements for both liquid-liquid and solid-liquid agitation, including PJMs as follows:** • **Re-suspend settled solids and maintain suspension of solids within vessels,** • **Provide blending of cold chemicals with active process liquids,** • **Sufficiently mix the contents of the vessels for sampling, and** • **Provide for the blending of cold chemicals with water for dilution.** **Detailed requirements, useful for design are not presented consistently in various documents or consistently.**
N	**Preliminary technology feasibility engineering report completed**	***Overview of the Pulse Jet Mixer Non-Newtonian Scaled Test Program* (24590-101-TSA-W000-0004-114-00019): This is summary report of the PJM testing program to provide technology data to support the design of the non-Newtonian vessels.** **The technology feasibility of the low solids containing vessels has not been established through an experimental program.**

Table C.9. (cont'd)

Complete	Criteria	Basis
Y	Integration of modules/functions demonstrated in a laboratory/bench-scale environment	A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.
Y	Formal control of all components to be used in final system	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Configuration management plan in place	The WTP engineering processes include procedures for preparation of engineering drawings (24590-WTP-3DP-G04B-00046, Rev. 16), review of engineering documents (24590-WTP-3DP-G04T-00913, Rev. 5), design change control (24590-WTP-3DP-G04T-00901, Rev. 10), design verification (24590-WTP-3DP-G04B-00027, Rev. 8), and other engineering department procedures. The WTP work processes are also controlled by a configuration management plan (24590-WTP-PL-MG-01-002, Rev. 4).
Y	Risk management plan documented	The WTP project has a formal risk management plan (24590-WTP-PL-PR-01-003, Rev. 3) and periodically assesses technology and programmatic risks to the project (24590-WTP-RPT-PR01-006, Rev. 13).
N	**Individual process and equipment functions tested to verify that they work (e.g., test reports)**	**A range of test platforms were tested to evaluate PJM Scaling Relationships for high-solids containing fluids. Tests were conducted in three scaled 4PJM test stands using Laponite and kaolin-bentonite simulants at large-, 1/4-, and 1/9-scale. PJM cavern heights, breakthrough velocities, and upwell velocities were obtained. These results were used to provide a technical basis for scaled testing. The technical basis for testing scaled PJM systems with non-Newtonian slurries is reported in WTP-RPT-113 and WSRC-TR-2004-00430.** **No testing has been completed for lower solids containing fluids.**

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Appendix D – Participants in the TRL Assessment

Appendix D
Participants in the TRL Assessment

Tables D.1 and D.2 provide lists of participants in the Technology Readiness Level Assessment for Pretreatment Facility for each individual critical system evaluated. The participants are divided into the Assessment Team and the Waste Treatment and Immobilization Plant (WTP) Project Technology and Engineering support teams.

The Assessment Team was compromised of staff and consultants representing the U.S. Department of Energy (DOE), Office of River Protection (ORP) (Hanford Site) and Office of Project Recovery (DOE Headquarters).

The Assessment Team was assisted by WTP Project Technology and Engineering teams comprised of subject matter experts associated with the critical technology elements that were being evaluated. These subject matter experts were either responsible for testing the technologies or incorporating the technology design into the WTP. In general, technology testing is managed by staff from Washington Group International (WGI), and engineering of the systems is managed by staff from Bechtel National, Inc. (BNI).

Table D.1. Participants in the Technology Readiness Level Assessment for the WTP Pretreatment Facility

Name	Affiliation	System Evaluated					
		Cesium Nitric Acid Recovery Process System (CNP)	Cesium Ion Exchange Process (CXP)	Waste Feed Evaporation Process (FEP)	Waste Feed Receipt Process (FRP)	HLW Lag Storage and Feed Blending (HLP)	Pulse Jet Mixers (PJM)
Assessment Team							
Alexander, Don	DOE/ORP	X	X	X	X	X	X
Holton, Langdon	ORP-PNNL	X	X	X	X	X	X
Johnson, Mike	CH2M Hill Hanford Inc.	X	X	X	X	X	X
Sutter, Herb	DOE EM Consultant	X	X	X	X	X	X
WTP Project Technology and Engineering							
Barnes, Steve	WGI-Process Technology						X
Corriveau, Clarence	BNI-System Engineer				X	X	X
Damerow, Fred	WGI-Process Technology	X	X	X	X	X	X
Lee, Ernie	WGI-Process Technology		X	X	X		
Olson, John	BNI-System Engineer	X	X				
Papp, Ivan	BNI-Process Technology						
Peterson, Reid	PNNL-Process Technology	X	X	X	X	X	
Saunders, Scott	WGI-Process Technology	X					
Slaathaug, Eric	BNI-Process Technology			X		X	
Sundar, P. S.	WGI-Process Technology						
Thorson, Murray	WGI-Process Technology	X	X				

Table D.2. Participants in the Technology Readiness Level Assessment for the WTP Pretreatment Facility (cont'd)

Name	Affiliation	System Evaluated					
		Pulse Jet Ventilation System (PJV)	**Pretreatment Vessel Vent Process System (PVP)**	**Plant Wash Drain (PWD)**	**Treated LAW Evaporation Process (TLP)**	**Ultrafiltration Process (UFP)**	**Flow Sheet/Process Control**
Assessment Team							
Alexander, Don	DOE/ORP	X	X	X	X	X	X
Holton, Langdon	ORP-PNNL	X	X	X	X	X	X
Johnson, Mike	CH2M Hill Hanford Inc.	X	X	X	X	X	X
Sutter, Herb	DOE EM Consultant	X	X	X	X	X	X
WTP Project Technology and Engineering							
Barnes, Steve	WGI-Process Technology	X	X	X		X	
Corriveau, Clarence	BNI-System Engineer	X	X	X			
Damerow, Fred	WGI-Process Technology	X	X	X	X	X	X
Lee, Ernie	WGI-Process Technology	X	X	X	X	X	X
Olson, John	BNI-System Engineer						
Papp, Ivan	BNI-Process Technology						X
Peterson, Reid	PNNL-Process Technology				X	X	X
Saunders, Scott	WGI-Process Technology						X
Slaathaug, Eric	BNI-Process Technology				X	X	
Streiper, Ed	BNI-System Engineer			X			
Sundar, P. S.	WGI-Process Technology					X	X
Thorson, Murray	WGI-Process Technology						X